Bells and Their Music

With a Recording of Bell Sounds

WENDELL WESTCOTT

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Of all the sounds man has introduced into the world, perhaps those most pleasing to the ear and most adaptable to all cultures are the sounds of bells and carillons. While the traditional purpose of bells has been for signals and proclamations, sounds to broadcast the time of day or announce impending action, over the centuries they have been developed into instruments of high musical qualities.

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About the Book

Of all the sounds man has introduced into the world, perhaps those most pleasing to the ear and most adaptable to all cultures are the sounds of bells and carillons. While the traditional purpose of bells has been for signals and proclamations, sounds to broadcast the time of day or announce impending action, over the centuries they have been developed into instruments of high musical qualities.

What appears to be a trick photograph is actually a lineup of the 66 bells of one carillon.

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The Czar Kolokol (Emperor Bell) resting on a pedestal at the foot of the Tower of St. Ivan in the Kremlin, Moscow. Fire damaged the bell while it was still in the casting pit in 1737, and the bell has never been rung. The damage is on the side to the tower.

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MUSIC ROOM

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1 Bells of the Orient

THE RINGING VOICES of bells have comforted man in time of despair, warned him of impending danger, and accompanied him in battle, in revelry, and in worship.

The origin of bells is shrouded in the mist of antiquity. We can imagine, though, that early man first stumbled on the discovery that striking objects around him—stone, wood, shell, horn, or bone—produced a pleasing resonance. Before long, a rhythmic beat was used to accentuate the ritual of tribal dances.

As time went on, it was found that cured animal skin, stretched over a hollow log, emitted a sonorous boom when beaten. A tone of definite pitch could be produced by blowing through a hollow bamboo or reed. Resilient pieces of wood clacking against one another were used as a rattle, and a dried gourd containing loose seeds was a natural percussion instrument.

Achieving a true ringing sonority, however, had to

Unique version of the deep-dish gong (or bronze drum or kettle gong). First appearing among Miao tribes of the Indochina region about the time of Christ, the deep-dish gong is still used in rain rites.

Facsimile of elongated bowl-shaped Chinese temple bell with scalloped lip. Hole in dome at left center is for tonal purposes and supposedly to prevent fracture. The Great Bell of Peking, of this form, is covered inside and out with inscriptions from Buddhist classics totaling 160,000 words. Cast about A.D. 1420, the Great Bell of Peking still rings in a Buddhist monastery on the outskirts of Peking.

await man's discovery of how to smelt the ore of metals, such as copper, tin, and zinc. The development of this skill ushered in the Bronze Age around 3000 B.C. According to the Bible (Genesis 4:22), the first forger of metals was Tubal-cain (*c.* 3800 B.C.).

Copper, the earliest metal to be used extensively, was initially fashioned into such basic articles as utensils, tools, weapons, and personal ornaments. The primitive artisans would have hammered or cast shapes that produced varying degrees of reverberation when struck. It must have been apparent that certain pots, bowls, and plates gave forth a more pleasing sound than others. In time, man mastered the technique of fusing copper with other metals, producing a stronger and more rigid alloy; the resulting tone was even more delightful. Man had developed a new substance with a special characteristic which was destined to play a unique role in all future cultures.

Precisely where bells first appeared is unknown; both Eastern and Western Asia have been claimed as the area of origin. Whatever the case, the entire civilized world of antiquity was eventually acquainted with numerous forms of metallic ringing objects, and the pattern of their use was universal to a large extent.

Bells and gongs, often in combination with drums and other musical instruments, have long been used to accompany the dance, and jingling-type bells often adorned the dancers themselves. The use of bells on domestic animals is also of ancient origin.

The Chinese of antiquity were successful in controlling the pitch of bells as well as sets of stone slabs, and both were used to produce music. Inevitably, these appealing sounds became integrated into the rituals of worship.

In all religions throughout the ages, ecclesiastics have sought to create an environment that would enhance spiritual communion by appealing to the senses, both emotionally and aesthetically. The bell held a certain aura of mysticism, as if it contained hidden spirits that communi-

cated with the living by means of an enigmatic language, one intermittently plaintive, ominous, stern, or reassuring. From earliest times, the indefinite fading of a ringing tone has been associated with the infinite.

In the Asiatic world the basic shapes of the shallow plate, the rounded pot, and the deeper bowl appear to have been the precursors of the cymbal—thought to have originated in Turkey—the gong, and the barrel-shaped bell. Traditionally, two cymbals were clashed together, making a strident clanging noise of indeterminate pitch. The large deep-voiced gong conveyed the very essence of foreboding, although smaller ones of higher pitch could charm the ear. The bell itself was capable of emitting a vast spectrum of sounds, from sweet delicate tinklings to thundering reverberations.

In the hands of the ingenious Oriental, the bell became a truly diversified instrument. It was made of various metals and fashioned in many shapes—square, rectangular, round, elliptic, pointed elliptic, and in the form of a bowl, cup, barrel, or lotus, with either straight or irregular rim. It was hung in a fixed position (a suspended bell is never swung) or held in the hand. It might be struck from either the inside or the outside, or jingled. Bells were fastened on animals and conveyances, or used to decorate garments; they were suspended from the neck as amulets and worn in series as a necklace or an anklet. As metal-casting techniques improved, the size of bells increased, and even in ancient times the Chinese cast bells weighing many tons, which were suspended before temples and palaces.

The Oriental of Eastern Asia has always favored using a mallet or hammer to strike a bell on the outside. If a bell is too large for this to be practical, a heavy wooden ramrod, suspended from chains, is swung so that it strikes a medallion cast in the bell's wall near the rim. In this part of the world suspended temple bells are always devoid of clappers. Only small wind-bells and some handbells contain clappers.

Ancient Assyrian bell from the ruins of Nineveh.

A crotal, the oldest type of bell known to man.

The Mingun Bell, near Mandalay, Burma, with a shape more European than Oriental, is the world's largest ringing bell. It weighs 97½ tons and has a diameter of 16 feet, 3 inches. Cast in 1790, it has survived two earthquakes.

Bronze Chinese temple bell of the fifth century B.C. (Chou Dynasty). Elliptical in shape, it has four fields of nine bosses in the form of coiled serpents. The handle is formed by two intertwined dragons, and the bell is decorated with intricate geometric patterns.

Interior temple bells are usually hung from a stylized, rectangular framework of wood, which stands on table or floor and can be moved about at will. The main temple bell, which generally ranges in height from two to five feet—although some are much larger—is also suspended from a framework, but this is located in the temple court and housed in a stone or wooden pavilion or tower. Customarily, the temple bell is rung in rapid repetition for several minutes at the beginning and end of services. On special ceremonial occasions, such as the annual spring and autumn sacrifices, a huge drum is also used in the rites.

Public bells and drums are not confined to the temples. Since 2000 B.C.—or even earlier—a notable feature of all Chinese cities has been their drum and bell towers. Both drum and bell announced the time of day and warned of fire, flood, or approaching enemy. The public drum, bell, and gong have traditionally been considered indispensable by the Chinese people, and no palace, temple, or other official building was ever without them.

In India during the second century—and later in China—a picturesque structure of great architectural beauty appeared. It was called a pagoda. Often rising to several hundred feet in height, it was usually from seven to thirteen stories (always an odd number) with upturned eaves. At each corner small wind bells were hung; the slightest breeze would swing the clapper and cause a melodious tinkling. It is said that these bells were originally intended to frighten away not only birds but also any lurking evil spirits.

Often there are hundreds of these bells—the pagoda at Tung-chow has about a thousand—and their infinitely varied tinklings create a veritable symphony of sound. Sometimes the pagoda is a Buddhist temple, but more often it is a memorial tower or shrine, built within a temple compound. In China and nearby countries, some 2,000 of these pagodas are still in existence today.

Wind bells are not limited to pagodas. They are also

hung under the corners of roofs of temples, palaces, pavilions, and private homes. The wind chimes you sometimes see in a house or on a porch in America have their origin in this ancient Oriental custom.

The Chinese learned that certain varieties of marble, including jade, produced ringing tones when struck, and so stone chimes were incorporated in religious and social ceremonies. The stones were formed in L-shaped slabs, and in the course of time the Chinese developed them into sets of sixteen, suspended by cords in a wood framework. They were struck with padded mallets to produce tones. At first, the size of the stone determined its pitch. Since the Middle Ages, the stones have been the same size and the pitch regulated by the thickness, which varies from stone to stone.

Bell chimes also appeared in ancient China. They were probably one of the earliest applications of the metallic cup-shape. Consisting, at first, of six to twelve bells, they evolved like their stone counterparts into sets of sixteen contained in a similar framework. Originally, size determined their pitch, but during the Ming period (A.D. 1368–1644) size became uniform and thickness the pitch-controlling factor—as with the stones.

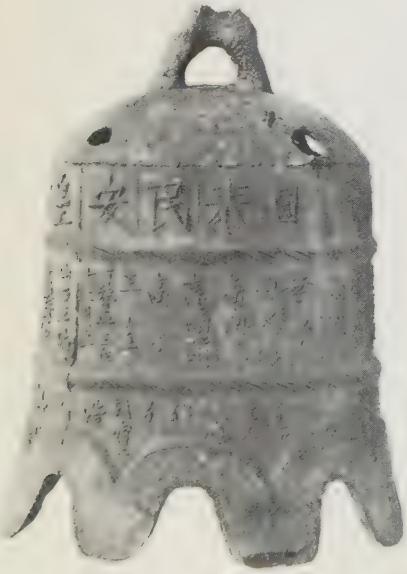
The earliest interior temple bells were rectangular in cross section, but during the Chou Dynasty—or at least by 600 B.C.—the pointed ellipse was adopted, and at different times both the arched and the straight rim have been employed. Older bells each had a round tapered handle with a projecting loop near the base through which a cord was passed for hanging. This loop was often formed by a stylized tiger or a dragon swallowing its tail. Later, the handle was replaced by two intertwined dragons or other hideous animals, which also formed a loop. The handle was not only a means of suspension, but the creatures forming the handle were regarded as the bell's protectors, for the bell itself was a major religious symbol.

During the Ming period temple bells were round and probably straight-sided, but subsequently they became

In the late nineteenth century, Dr. Liu Ming-chih photographed marble chimes (above) and bronze chimes (below) in front of a Confucian temple in Hangchow. These reproductions were rephotographed from a publication of the Royal Asiatic Society of more than fifty years ago. Each chime is accompanied by a gong, hung in a narrow frame alongside.

Bronze Chinese temple bell of the Chou Dynasty (1122–255 B.C.). An interior bell, handle and bosses indicate it is from the early Chou period.

Cast-iron Buddhist temple bell, dated 1595. Iron was often used during Ming Dynasty (1368–1644) because bronze was expensive and in short supply. Although an excellent casting, the bell falls short of Chou period craftsmanship.



barrel-shaped and, in more modern times, elliptical. The popular barrel-shaped bell, ranging in size from a few inches to several feet, originated in the Chou period (1122–255 B.C.). It is similar in shape to the barrel drum, which is often associated with it and is also of ancient origin.

In addition to stationary bells, small ornate handbells with inside clappers have a part in temple ceremony. These are rung by Buddhist and Taoist priests during services, in conjunction with cymbals, gongs, drums, and other instruments. The "resting bell" is another traditional type, dating from the Middle Ages. This is nothing more than a metal bowl from one to two feet in diameter, placed open side up on a cushion in front of the principal shrine in the Buddhist or Taoist temple, and struck at the edge with a wooden stick.

In the Orient temple bells have traditionally been ornamented with symbolic decoration. In China the upper wall of the bell invariably displays rows of spikes or rounded bosses in clusters of nine in four square fields encircling the bell—nine being considered in Buddhism a mystic number signifying renewal. The bosses, which sometimes are in the form of a coiled serpent or dragon, have been interpreted as having various meanings: they are said to represent fertility hovering over the plain field below, in which is the seed; they suggest the sun's rays shining through the tree of knowledge onto Buddha's shaved head; they represent the sacred snails covering Buddha's head to protect it from the sun. Whatever their symbolic meaning, they have been filed to alter the bell's pitch—which was probably their original function.

The lower area of the bell is sometimes plain but more often decorated with intricate, interlacing geometric designs, usually based on animal motifs; other bells are inscribed with prayers, the maker's name, or even the names of those who have contributed to the bell's purchase.

The bell rim is also treated. Characteristic are the

angular or rounded indentations forming a scalloped edge, which is the identifying mark of the popular lotus-shaped bell. Buddhists consider the lotus a sacred flower, symbolizing purity, mercy, fruitfulness, and long life.

The Oriental attitude toward bells has always been one of deep reverence. It was believed that bells could cast or remove a spell, increase fertility, or even house a spirit. According to traditional belief, bell ringing *purified* the holy place. In the Buddhist temple, as in the Christian church, there is a consecration ceremony (in this case involving animal sacrifice), after which the bell becomes a sacred object. When placed on animals, the bell afforded protection against evil spirits, even as it did when hung at the door of a house.

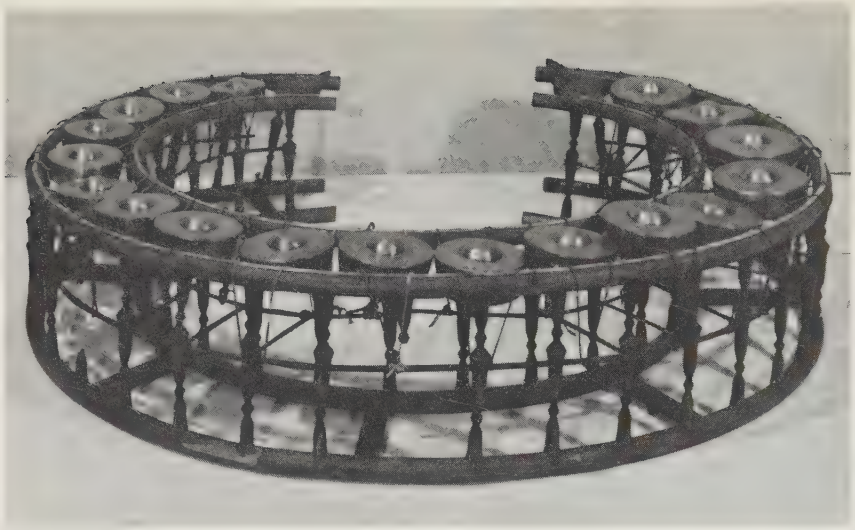
Of all religions, only Mohammedanism and Judaism have refrained from using bells. Mohammedans frowned on the bell's long association with pagan rites and beliefs, and in Judaic practice the shofar, or ram's horn, and the metal trumpet have always served.

Although Biblical references to bells are meager, their use on a high priest's robe is mentioned in Exodus 28:33–35. Clearly, this alluded to the crotal, a small round ball (gold in this instance) containing loose pellets. Of ancient origin, the crotal has remained unchanged over the years and is found throughout the world. Crotals are also suggested in the mention of "bells of the horses" in Zechariah 14:20, the only other definite Biblical reference to bells. Biblical mention of cymbals, on the other hand, occurs frequently.

In the Middle East the Egyptians, Assyrians, Jews, and

Bronze temple bell of Han period (206 B.C.–A.D. 220). Although retaining some Chou features, the general craftsmanship is inferior, the handle plain.

Set of gongs, called koulintaugau, from Borneo.



A khong thom from Cambodia. Gong instruments of Southeast Asia have either circular or rectangular frameworks. This instrument has eighteen bronze gongs of graduated sizes. It produces a heptatonic scale of seven equal steps. The gongs rest on leather thongs stretched over a bamboo cradle, and are played with wooden mallets.

Japanese shoko gong, an instrument in the orchestra that usually plays the traditional gagaku, or court music.

others made various use of bells. The ruins of Nineveh, at Nimrud, have yielded about eighty small bronze bells dating about 655–612 B.C. The Roman historian Flavius Josephus wrote that King Solomon had sizable bells of gold placed atop his temple to drive off the birds. Golden bells adorned the mules used in the funeral procession of Alexander the Great. And the packhorses, mules, and camels of the caravans were equipped with bells. Both master and beast of burden were cheered by the bells' gay tinkle; bells helped to locate stray animals—and guided any masters who themselves strayed.

In Greece the opening of the fish market was announced with bells. Priests used handbells in pagan rites. When a king died, women walked the streets striking bells. And in the Peloponnesian War (431–404 B.C.) bells were fastened to sentries' uniforms for signaling purposes.

The Roman infant played with a toy bell, and a bell was tolled when life ended. Its sound accompanied the criminal to his execution. Dancers and harlots were festooned with bells. The ringing of bells regularly notified the populace when the public baths were ready for use. Following the Greek example, the Romans also made fre-

quent military use of bells, attaching them to their chariots or to themselves, or hanging them in camps as warning devices. The first Emperor Augustus (63 B.C.–A.D. 14) hung a bell before the temple of Jupiter.

The unique Bells of Justice originated with the Chinese and are said to have existed ever since—perhaps more in legend than in fact. In order that their lowliest subjects might have recourse to justice, benevolent potentates often placed bells outside the palace gate or in some other appropriate spot. Anyone seeking redress could ring the bell, but woe to him who rang without proper cause. In Longfellow's tale "The Bell of Atri" the bell rope was pulled by a horse!

There are endless examples of the use and importance of bells in human affairs throughout the ages.

As the various metallic forms were developed, they were spread around the civilized world through the burgeoning channels of commerce. Gongs, cymbals, and bells of moderate size were easily transported from place to place. Sometimes made of gold and silver, these objects were prized as gifts for exchange between kings, and wealthy nobles or merchants. Consequently, we cannot always be certain where basic types first appeared. But it is evident that brass, bronze, gold, silver, iron, and other metals—even lowly clay and select woods and stones—were the materials fashioned into shapes and sizes whose ringing tones found universal favor as accompaniment to ritual, dance, and popular festivity, or use for human or animal adornment. Bells were rung in triumph or alarm, in everyday life as well as in celebration and battle, in joy or in sorrow.

But bells had never swung in lofty temple belfries. The Judean "sound of the trumpet," the clash of pagan cymbals, the ringing in streets of handbells to announce the Roman baths or call people to markets or fairs—were among early forms of signaling. In later times they were followed by the vibrant swinging bell on high, which was to become an everlasting symbol of Christendom.

The Great Bell of Kyoto, weighing 74 tons, is the second-largest ringing bell in the world. It is sounded by a heavy wooden ramrod, suspended from chains and swung by sixteen priests. The ramrod strikes a medallion on the bell's lower wall. This is the main bell in the largest Buddhist temple in Japan, the Chion-in Temple.

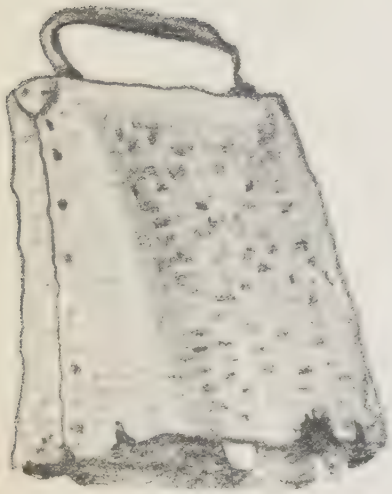
The pavilion housing the Mingun Bell. (Location of the bell, concealed in the shadows, is indicated by the dark silhouette in the sketch at left.) The customary suspension of the Oriental bell for announcing worship is in a low wooden or masonry structure, with the bell a few feet off the ground.

Spanish monk "tapping the cymbala." (Miniature from The Cantigas de Santa Maria, written by Alphonso the Wise in the thirteenth century.)

2 Church Bells of the Early Christian Era

THE EARLY Christians of Rome met and worshiped in secret because of intermittent persecution by the state. Naturally, it would have been foolhardy to proclaim their presence by placing bells in fixed locations outside their meeting places, since discovery could mean possible death. Furthermore, bells had not been accepted as a Christian symbol at this time; their long association with pagan ritual and secular practice, in both Greece and Rome, made their use in this budding religion seem inappropriate. Handbells, however, had been surreptitiously introduced to some extent as a means of announcing or opening services.

When Constantine the Great (A.D. 278–337), the first Roman emperor to recognize Christianity, gave it official status, A.D. 313, it received increasing acceptance until it was finally adopted as the one legal religion of the Empire



Old English church bell of hammered iron.

toward the end of the century. Now the long-established association of bells to signal the opening of events or mark moments of prayer in the temple—ancient Asiatic practices adopted by the Greeks and Romans—was to reassert itself in the new religion. Moreover, the bell's mystical connotations could not be ignored as an important element in appealing to the imagination of the populace.

Knowledge of the earliest mounted bells in the Christian Church is meager; traditionally, Paulinus (353–431), bishop of Nola in Campania, Italy, is alleged to have introduced the first tower bell toward the close of the fourth century—to be rung as a summons to worship. Actually this is probably inaccurate. Records indicate that bells had already been placed in church towers, or at least in elevated exterior locations (on a framework in the churchyard, on the church roof, in a tree, and so on) for some time. Indeed, in a contemporary account describing the bishop's church in some detail, there is no mention whatever of bells! But it is definitely established that by the fifth century tower bells were becoming widespread and firmly rooted as a fixture of the church.

With the status of Christianity no longer precarious, and its practice spreading north from Italy, handbells and—soon afterward—larger tower bells accompanied the establishment of new monasteries and churches. Bells are frequently mentioned in the writings of French clerics during the sixth century, including an account by St. Gregory, bishop of Tours (573–595), referring to their various liturgical uses.

Sabinianus, who became Pope in 604, is said to have been the first to order bells rung to indicate the canonical hours—the eight periods of prayer and devotion—in the monastery. It is possible that this practice was not entirely unknown at that time, but in any event his encouragement helped to popularize it.

St. Patrick (*c.* 389–446) is credited with introducing handbells to Ireland around 432. He had brought metalworkers with him to fabricate the bells for his new monas-

teries, and it is thought that he supplied the Irish church with no fewer than fifty. Relics of these early bells can still be seen today in Irish museums; they are encased in elaborately carved brass shrines and are highly revered. Most famous is the Bell of St. Patrick's Will, a rectangular bronze-dipped iron bell, six inches high, five inches wide, and four inches deep, made of two bent plates riveted together. None of St. Patrick's bells were cast; they were fashioned from one or two sheets of iron hammered into shape (never round) and dipped in bronze. Although bronze-dipping was thought to improve the tone, today we would consider it about comparable to the sound of an ordinary cowbell. Evidence indicates that at first these bells were struck with a small hammer or mallet but an inside clapper was later added. Primitive as they seem today, St. Patrick's bells nevertheless served a noble purpose in regulating life in the monastery as well as in attracting potential converts.

Bell towers were not added to Irish monasteries until the following century, and the first bells they housed were little different from the handbells carried by the monks. Although slightly larger, they were still fashioned of iron plates, and their purpose remained the same. It might be said that the fixed hanging of bells at an elevated point was the first humble step leading eventually to their automation.

From the sixth century onward, monasteries and churches—and their bells—spread in increasing numbers throughout Europe, in spite of the prevailing political turbulence and general social instability. This was the period known as the Dark Ages. During this time, the most profound association of bells was their religious function. In a superstitious age it was natural they would give rise to numerous legends concerning their powers to heal or cast a spell and to other folklore. Now the Oriental's high esteem for bells and keen interest in them was shared by the European.

The monasteries became the sole ray of light on a dark

An Italian bell of the early fifteenth century.

Above: Shaping the core (inner mold) with a strickle board, or sweep, at the Whitechapel Foundry, London.
Below: Forming the cope (outer - mold) of a carillon bell.

horizon. They were the center of learning, concerned not only with theological matters but with every sphere of human endeavor, including the arts and sciences, the various crafts—and bell making. No matter how remote a monastery might be, its bell was the symbol of progress and hope, and it became increasingly important that it be heard by everyone—layman as well as cleric. This alone would have demanded bells of better quality and resonance. But there were also further changes taking place. The church, once situated within the monastery walls, was now often built in a central location, around which the municipality grew. Rising cities and expanding population gave added impetus to the creation of church bells whose sound would reach the outermost limits of the community.

For reasons none too clear, there was no casting of bronze bells in Europe for several centuries; only hammered-iron bells were made for church use. It seems unlikely that the art of casting could have been entirely lost in the West; it had certainly been known to the early Romans and was firmly established throughout the civilized world, including several areas of Europe. It is quite probable, however, that casting facilities were lacking in the remote sections traversed by the missionaries. Also, the necessary copper and tin might not have been available—tin especially was in short supply. It has even been suggested that casting may have been avoided on religious grounds. There was a stigma attached to all objects cast in bronze because statues and idols of pagan Rome had been made in this way.

Whatever the reason, there is no record of circular cast bells during these first centuries of the expanding Christian church.

By the seventh century, church bells had become commonplace even in the villages of Western Europe. The Venerable Bede (*c.* 673–735), considered the most learned scholar of his time, seems to have made the earliest mention of them in England, when he wrote that

Benedict Biscop brought a bell from Italy for Wearmouth Abbey, to be used—among other things—for awakening, to call to prayer, and to toll for the departed. Early in the same century (although some claim later), cast bronze bells made their first appearance on a limited scale in Western Europe. It can be said that this development marked the beginning of the evolution of the type of bell that reached an advanced stage in the fifteenth century—having the same basic form commonly seen in belfries today.

Finishing the cope.

Although, on the Continent, bells of hammered iron occasionally attained some degree of roundness and symmetry, it was only with the casting technique that a bell's shape could be precisely controlled. The earliest cast bells probably retained the quadrangular shape of their predecessors, but quality of tone must have been improved a good deal because of the greater resilience and thickness of the new metal—an alloy of copper and tin. At any rate, by the eighth century cast bronze bells had largely superseded the iron, although iron bells were still made and continued to be used for some time. The squared shape

soon gave way to the round form for all subsequent church bells.

Two distinctive bell forms now developed: the cup-shaped, shallow bell, clapperless and struck on the outside with a hammer, and the deeper "beehive," or roughly conical form, with convex wall of uniform thickness and an inside clapper. The former, generally of small size, came to be called *cymbalum* (medieval Latin for *bell*), and this was the one with which the medieval monks experimented in their efforts to create a series of musical tones. For not long after bell casting had been undertaken under the auspices of the monasteries, efforts were made to control pitch, which soon led to the development of a new musical instrument—by the ninth century if not earlier—for clerical use.

Although complete knowledge of their uses is lacking, these bells are thought to have accompanied the chant and to have been played independently in a melodic way, probably at the beginning of divine worship. It is also presumed that their fixed pitches—mostly in diatonic order—made them useful in the teaching of singing. But whatever their musical use, they were the subject of continuing experiments in which their physical properties were analyzed and knowledge was gained that led to major modifications in bell making.

The cymbala, never more than a foot high, were suspended at about shoulder height from a crossbeam in the church or monastery cloister and were almost invariably rung by striking them with hammers. Spreading throughout Western monasteries, this practice gave rise—beginning in the ninth century and continuing into the fourteenth—to numerous illuminations of the Psalters, hand-drawn by the monks, which show representations of cymbala being played, often in connection with Psalm 150. These illustrations depict King David or the monks themselves, mallet in each hand, "tapping" a row of bells suspended from a beam, often accompanied by the organ

or other musical instruments of the time. Anywhere from three bells to a maximum of fifteen are usually shown.

A departure from the usual method of cymbala ringing by tapping is shown in a thirteenth-century Spanish illumination from the *Cantigas de Santa Maria,* a book of musical poetry by Alfonso the Wise, which contains descriptions of contemporary musical instruments. Here a seated monk is shown ringing a set of seven bells by pulling cords attached to inside clappers; this in fact became a common practice in England, where it was called "clocking," since its purpose was to mark the time.

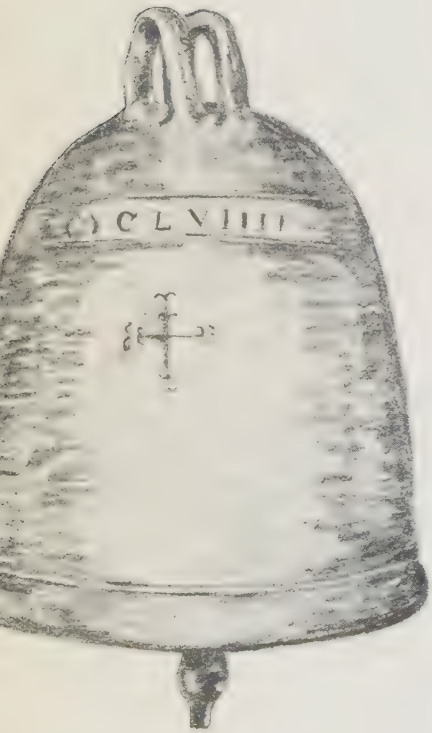
The ritual of the Christian church placed great emphasis on symbolism (in common with similar practice in the Orient), and eventually the cymbala and other musical instruments assumed certain symbolic connotations. Perhaps the delicate, high-pitched sound of the cymbala and handbells was responsible for their particular association with paradise, or the heavenly. During the twelfth century they were attached to organs and played from the regular keyboard by means of wire connections to inside clappers. This arrangement—the organ's first chime-stop—was prevalent in much of Europe for a time, but eventually proved unsatisfactory and disappeared. However, it did lead to a similar keyboard play of cymbala, apart from the organ. But this indoor instrument was also short-lived. On the other hand, the rich spicy timbre of these early bells served as inspiration for the later organ mixture-stop, called *zimbel.* Furthermore, the name *clavicymbalum,* applied to the earliest plucked-string keyboard instruments, resulted from their similar tonal nature.

Aside from the intriguing scenes depicted in the Psalters and other volumes, a number of treatises written at the time mention the monks' experiments with bells. One of the earliest works of this kind is a detailed description of the casting of a bell and the problems of its harmonics, written by the Benedictine monk Theophilus Presbyter in the latter part of the eleventh century. This work and

Church Bells of the Early Christian Era

Above: The cope being fitted to the core. Below: Tuning the bell. As it revolves, metal is ground from the interior in some areas.

subsequent treatises indicate the concern at the time for proportions and the proper mixture of copper and tin for producing the best ring; furthermore, there was at least a basic understanding of how to change a bell's pitch by varying its dimensions and wall thickness. Even the relationships of a series of bells forming the scale were computed according to weight and diameter, helped by comparison with the measurements obtained from the monochord, a one-stringed instrument used for experimental purposes. Nevertheless, there appears to have been no real understanding of bell harmonics during this period or any serious attempt to regulate them. This final phase in the search for the perfect bell was not seriously undertaken until the fifteenth century.

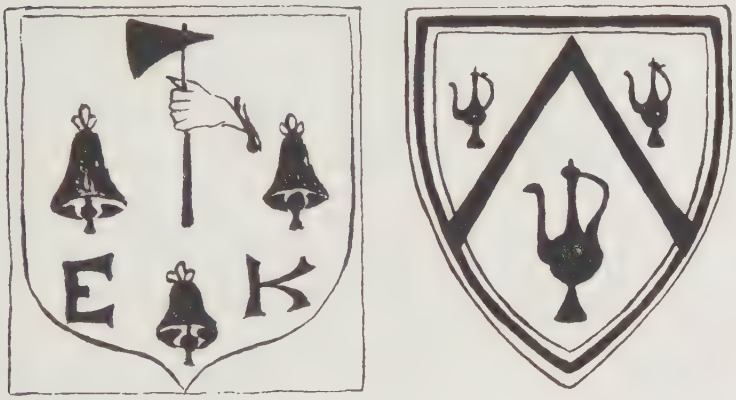


Church bell of Sienna, A.D. 1159.

Of the two bell forms mentioned earlier, the primitive "beehive" was favored for the larger bell in the church tower; its greater length was better suited to the pendulum swing of its clapper. The continuing changes made in bells from the eighth to the fifteenth century indicate a persistent groping for a profile or contour that would improve tone quality. This search, begun in the earliest days of bell casting, was pursued zealously over the years, reflecting the intense interest—first shown by church artisans and later by secular founders—in achieving the ideal bell.

As time went on, the primitive bell gradually underwent a transformation: first, its convex wall gave way to a straight and finally a concave form, which became longer-waisted and thicker-rimmed. As bells grew larger, it became necessary to strengthen the rim by adding a ring of metal around the outside as protection against cracking, for the clapper's resounding blow against the swinging bell often fractured the metal. Then it was discovered that such reinforcement produced a more resonant and musical tone. As a result, the reinforced rim was transformed into what is now known as the sound bow, a thickening of the wall somewhat above the edge.

By today's standards—or even those of the sixteenth century, for that matter—these early church bells were decidedly mediocre in tone. We are indeed indebted to the founders of the time, who apparently held a similar view, for without their efforts to create a more musical bell, the carillon could not have materialized.



Early English founders identified their work with distinctive seals rather than names or initials. These two seals are, left, Ellis Knight of Reading and, right, a medieval foundry.

The tower bell—now known as the archaic bell—which had developed by the eleventh century and continued with modifications into the fourteenth, was long-waisted with relatively straight walls of uniform thickness, very narrow-topped, of rounded shoulder, and flared at the bottom rather like a medieval jester's hat.

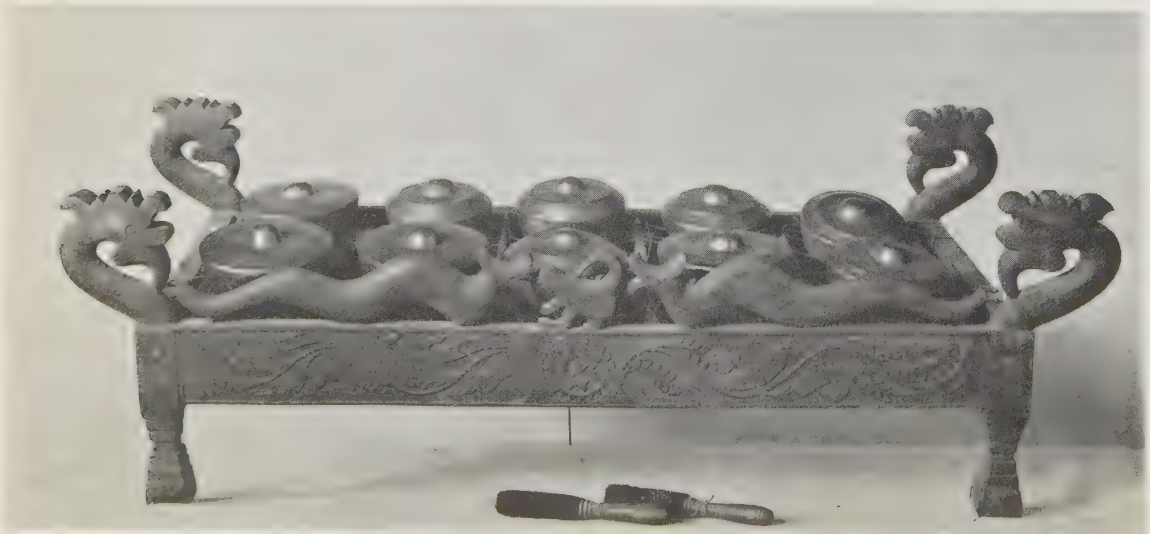
The thirteenth century was the bridge between this form and the beginnings of the modern bell. During that time, the sound bow developed, the head became broader, the shoulder became less rounded, and the height shortened in relation to bottom diameter. By the century's end an overall form starting to resemble the present bell had emerged, and it now remained to be perfected through strategic adjustments in proportion.

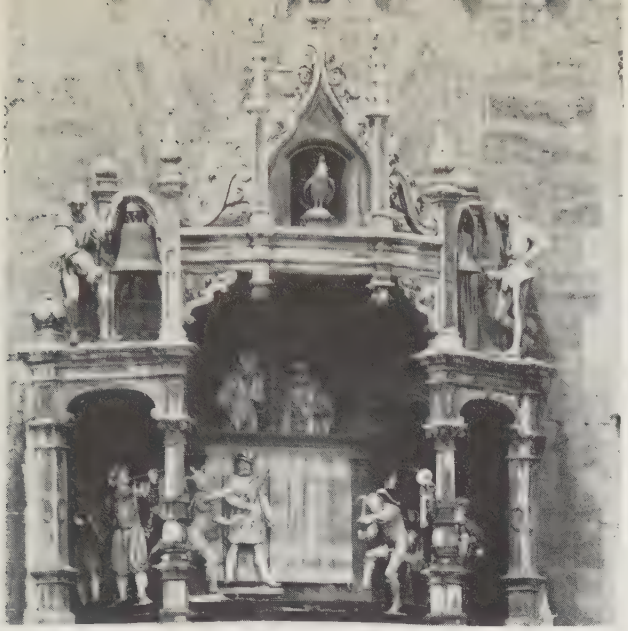
During the fourteenth century, as progress continued toward achieving truer pitch and clearer tone, bell profiles were further refined. By now, both in England and on the

Continent, series of bells capable of sounding melodies had begun to appear in belfries. When this innovation became more popular and widespread, efforts to perfect bells greatly accelerated. Toward the end of the century, intensive study of bell acoustics had established—at least in general terms—that a bell must contain three octaves (now called hum tone, fundamental, and nominal) plus a minor third above the fundamental. (In fact, even in the thirteenth century, founders had considered it necessary for a bell to contain these three octaves.) With this firmer foundation of technical knowledge, founders had at last discovered the secret of the bell. From this point until the middle of the seventeenth century, work proceeded on solid ground, culminating in the near-perfect bell, the superb product of the brothers Hemony of Amsterdam (see Chapter 7). It was well into the twentieth century before further improvements were to be made.

The fourteenth century seemed, indeed, to mark a turning point in the development of bells. It was now possible to cast tower bells weighing several tons. This was to lead, later, to rivalries between churches, and even cities, to see who could boast the largest bell. Perhaps by this time the artisans of Europe had learned that the Chinese had long since cast large bells, or perhaps economic conditions were more favorable. Certainly bells were a manifestation of the high level of development that many skills had reached by the time of the Renaissance—a period of even more extensive change.

Javanese bonang, one of many gong instruments found throughout Southeast Asia and neighboring islands. A leading instrument of the gamelan, or Javanese orchestra, it is played by a seated musician using mallets.





The 43-bell glockenspiel in the town hall of Munich is heard twice daily. Seven groups of animated figures perform at each ringing: a crowing rooster, two jousting knights, folk dancers, two bell strikers, a night watchman, a black-hooded "Mascot of Munich," and an Angel of Peace.

3 Bells During the Renaissance

THE EVOLUTION of the church bell in its lofty site can perhaps be seen in better perspective when related to the happenings on the earth below. After the fall of Rome in 476, there was a long interval of turmoil in Europe, during which Western civilization was under the domination of barbarian elements. This was the period of the Dark Ages, when first the Saracens and Magyars from the east, and later the Vikings from the north, repeatedly invaded Europe. War and devastation blighted the land, and the lot of most people was far from a happy one. For centuries the Catholic Church alone undertook the burden of preserving the cultural inheritance of Europe.

Then, in the ninth century, a new social order began to gain dominance. This was known as feudalism, whereby a landed class of powerful noblemen controlled vast domains on which serfs lived under their protection. While strife assuredly did not disappear, at least a semblance of order prevailed.

This state of affairs lasted about five hundred years, marked by a slow but substantial recovery of civilized pursuits, particularly the mechanical skills and the crafts, which had seriously deteriorated since about A.D. 200. Now many new cities were being chartered, and by the year 1000 most of the major European cities of the future had sprung into existence. And before long, several universities of later fame had their modest beginnings.

Along with this growth of cities there appeared in the twelfth and thirteenth centuries one of the finest styles of architecture the world had yet known—the magnificent Gothic structure, characterized by graceful vertical lines, the pointed arch, loftiness—and superb bell towers. This Gothic style was applicable not only to churches but to various public buildings, including town halls, castles, and palaces. But the church, especially, became a symbol of community pride and was the crowning physical achievement of the age.

At the very time this noble evidence of skilled craftsmanship was coming into being, all Europe was swept up in an historical undertaking—the Crusades. This lengthy military and religious effort, whose alleged purpose was to recapture the Holy Land from the Moslems, resulted in changes far different from those intended: commerce among cities increased, a powerful merchant class—the bourgeoisie—arose, and this grandiose uniting of forces in a common cause tended to unify populations. But most important of all, contact with the advanced civilization of the Middle East helped to accelerate a movement already under way—interest was being rekindled in the classical culture of the ancient past. This ushered in the important historical epoch known as the Renaissance—a rebirth of learning. Although no exact dates can be set for this humanist movement, it began in Italy during the fourteenth century and spread throughout Europe in the fifteenth and sixteenth centuries.

In the meantime—even as early as the fourteenth century—feudalism had begun to disintegrate, giving way to a

new order, the rise of the city-state possessed of great wealth and economic power. The impetus given business and commerce during the Crusades made trade an important factor in this wealth, and it flourished among cities everywhere.

All fields of human endeavor were caught up in the current of this awakened activity: the arts, literature, philosophy, science, education, architecture, construction, exploration, and every sort of known craft, including cabinetwork, clockmaking, metalworking, mechanical invention, stone masonry, glazing, and so on. At mid-fifteenth century Gutenberg invented movable type for printing.

Trade guilds that had arisen controlled and strictly regulated every craft and business. History records the birth of capitalism itself at this time.

One change of untold significance was the removal of the center of learning from the church to a secular environment. The momentum and scope of the intellectual revolution that was under way could not be confined within monastery walls, for too broad a spectrum of the population was involved—in truth, all Western civilization. Never again was the church to hold the sole cultural reins.

Now let's return to our main theme and trace the early development of the bell instrument called the carillon, which was a product of the Renaissance.

Interest in machinery had been increasing, particularly since the beginning of the eleventh century, and important advances were being made in metalworking. Some of the progress can unquestionably be traced to the Crusades (as well as to the Moorish influence from Spain), when Europeans were exposed to the superb skill of the Moslems, who excelled in such diverse fields as metalworking and casting, textiles, mosaics, porcelain, glazing, architecture, stone and ivory carving, and so on. The Turks were especially noted for their excellent cymbals, finely tooled swords, and suits of armor. Therefore, the extended contact and commercial relations with this

advanced culture during the period of the Crusades were bound to affect European artisans, who had already been engaged in meeting the requirements of growing cities besides providing the necessary accessories for the Christian expeditionary forces. These artisans were also involved with new types of machinery contrived for various purposes, among which was a new way of operating a tower clock.

Bell strikers in St. Mark's Square, Venice, toll the time, a medieval custom which still persists to a limited extent in other European towns.

The popular Roman public clock had been the clepsydra, an ingenious but simple device powered by a controlled outflow of water into a basin containing a float attached to the base of a vertical shaft. The toothed upper portion of this shaft engaged a geared wheel on which a clock hand was affixed. As the water rose, so did the float and shaft, which in turn revolved the wheel with its hand. Some of these clocks were even equipped with a bell that sounded periodically, making them history's first chime clocks.

The clepsydra had found its way into certain European areas under Roman dominion and continued in use over the centuries until superseded by a machinery-driven mechanism. It was said to have been amazingly accurate and was often favored over its successor, which lacked precision because its metal parts were subject to weather expansion and contraction.

Of course, at this time most of the towers in the cities had no clocks, at least in the sense of a dial with hands. Timekeeping was a duty entrusted to some municipal employee, who climbed up to the belfry at intervals during the day to strike a bell—perhaps then returning to such mundane chores as street sweeping. But mechanical ingenuity and creative imagination were to replace the town Johnnie, as he was called, with a mechanically operated, lifelike figure. More often than not, this bell ringer was a picturesque knight in armor. On the hour, he came to life and, hammer or battle-ax in hand, struck the bell beside him.

Many variations of this figure—or even groups of

figures—were contrived almost as much to entertain the populace as to provide a public service. Later, with the advent of clock dials, elaborate devices gained wide popularity and even the affection of the populace. Often these animated figures became more than bell strikers—they clanged cymbals, blew horns, and danced to the accompaniment of a bell chime.

The sound of the bell, then, was the customary time indicator. In most parts of Europe its signal was the chief—if not only—means of informing the public of the time of day.

Early in the thirteenth century some form of mechanical dial clocks made their appearance in towers; toward century's end, the weight-driven clock was invented. Such clocks had become commonplace throughout most of Europe by the middle of the fourteenth century. One of the most famous—the first of a series of three astronomical clocks—was installed at Strasbourg Cathedral about 1350. Near the dial was an elaborately operated cock that flapped its wings, raised its head, and crowed every hour—a masterpiece of mechanical ingenuity!

But the bell dutifully struck by the faithful knight did not disappear. Although competition was now formidable, the knight carried on quite as before, and a bell—or bells—continued to be used alongside the visual indication of time. Hundreds of such clocks can still be seen in Europe today, with their animated figures in medieval garb quaintly performing to announce the hour.

A new element now appeared—the chime tune. No longer were all towers limited to one or two bells; three, four, or more were being placed in belfries. To be sure, peals of *swinging* bells (pulled by rope) had been common since at least the sixth century. But with their mechanical bent, craftsmen had succeeded in devising yet another way to ring bells, besides mechanical doll figures.

The method was the revolving drum mechanism, invented early in the fourteenth century. This consisted of an often sizable cylinder (at first made of wood) with

projecting pegs placed at appropriate spots. As the drum revolved, these pegs tripped levers to release striking hammers. This automatic bell play became known by various names, depending on location. For example, in Flanders it was called *voorslag,* meaning forestroke. The Flemish, and shortly thereafter the Dutch, were to become greatly intrigued by the automatic ringing of bells and their musical use; in fact, they became more closely identified with this practice than any other people.

Setting a new tune on the chiming cylinder at the Oude Kerk of Amsterdam, the Netherlands.

The English term for these sets was chymme bells, derived from *chymbals,* the Anglicized version of *cymbala, medieval* Latin for bells. Thus, a tuned series of bells capable of producing melody became known as a chime. Both in England and on the Continent the revolving drum method of chiming to mark the hour or quarters remained standard procedure during the succeeding centuries, and it continues even to this day. A keyboard was later added for human play of simple melodies, but the art of the carillon was never to attain a major role in England. Instead, the ringing of bells was subject to a unique development during the fifteenth, sixteenth, and seventeenth centuries that was to become England's distinctive contribution to the sounds from the belfry. This was a special way of pealing, called change ringing, whereby a number of bells (five to twelve) are rung in orderly sequence according to a predetermined plan or "method." The bells are swung by means of a rope, one man to a bell.

The chiming cylinder was connected to the clock mechanism and set off periodically by the clock's works. Inasmuch as the cylinder's function was to lift heavy hammers preparatory to letting them fall against a bell, a great deal of force was needed to rotate this cylinder. Power was supplied by a heavy weight suspended from a cable wound around the barrel shaft; when a stay was released, the cable unwound, thus turning the barrel. The clock itself operated on essentially the same principle;

indeed, both mechanisms were usually made by the same craftsmen.

Now, for the first time in history, the skill of the clockmaker, combined with that of the founder, had made possible the mechanical execution of melody in the belfry. It appears that the accomplishments of these two types of craftsmen, with their related interests, reached a like stage of excellence at about the same time. Each was indebted to the other.

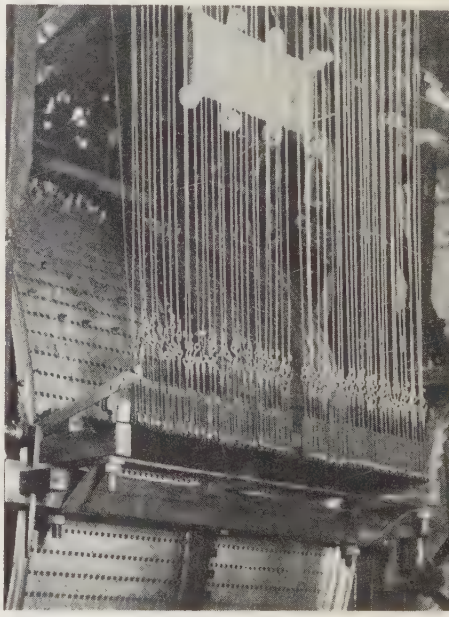
At first, the music of the chiming cylinder was of modest proportions. The early ones probably activated a maximum of eight to twelve bells, which permitted little more than a single melodic line. Tunes chosen at this time would have been limited to familiar folk melodies and spiritual songs, and it is likely that slight modifications were made in the event that a bell for a particular note was missing.

These clock chimes quickly gained popularity, and before long innumerable cities, towns, and villages throughout Western Europe ordered them for their belfries, in both town hall and church.

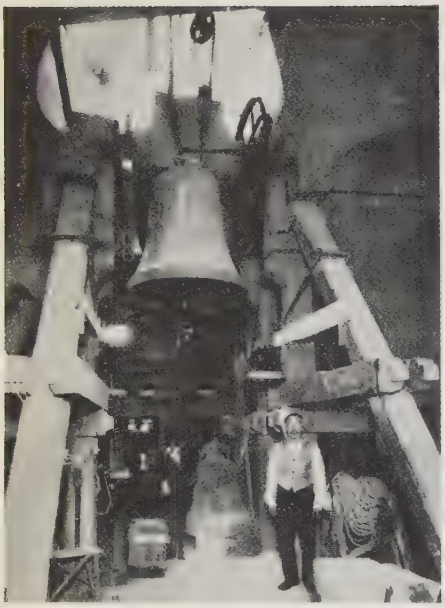
In the Lowlands especially, tower music had now become an established custom enthusiastically approved by everyone, and this provided founders with a strong incentive to extend the range of bells and broaden their musical scope. As time went on, more and more bells, operated by machinery, sounded together in towers, enriching community life with their appealing melodies. By mid-fifteenth century some sets numbered as many as eighteen.

Now let's digress for a moment and see what was happening to music in general as the fourteenth century gave way to the fifteenth. Vocal polyphony was coming into bloom, following its gradual development over the past five hundred years and paving the way for the rise of an instrumental music that was to have its beginnings in the following century. It may seem strange to us today

Chiming cylinder at the Nieuwe Kerk, Delft, the Netherlands, made in 1663. As the cylinder rotates, the projecting pegs trip levers which connect with the bell hammers. This has been the traditional method of automatic playing of bells since the fourteenth century.



that instrumental music was not emancipated from its subordinate role as a mere accompaniment to singing until this point in history. However, the fact is that many instruments had not yet been perfected to a degree that permitted any significant use. Therefore, no independent literature for instruments had yet been written. During the fifteenth and sixteenth centuries the lute, a plucked-string instrument, took the lead, later followed by the keyboard instruments—the harpsichord, virginal, clavichord, and organ—and joined by the bowed strings of the seventeenth century.



Oldest bell of the peal of six at St. Peter's Basilica in the Vatican is the della Rota ("of the wheel"). Cast sometime before 1354, it is one of the few archaic bells still in regular use in Europe. Even today Italian bells are relatively long-waisted.

The carillon's origin can be placed sometime after the mid-fifteenth century, and is thought to have been at Aalst, Belgium—although there is record of a very early instrument in Antwerp. This innovation, to be sure, represented no special inventiveness; rather, it owes its birth to a new *attitude* toward bells—a desire to explore their potential for a more expressive and personal musical style. The keyboard play permitted a flexibility of presentation not possible with the automatic chime, whose limited strains—heard repetitiously for weeks or months on end—were restricted by its clock association to a rigid schedule. Thus not only was a larger selection of music possible, but its time of performance could be fixed at will.

Other keyboard instruments had just come into being. While the organ at this time had reached a fairly advanced stage—it now had its pedal board—the concept of attaching a keyboard to strings, heretofore sounded only by plucking or bowing, was new. Consequently, a whole new family of clavier instruments was in the process of being introduced around Europe.

It is quite likely that the keyboard play of bells was influenced by this related string development, which occurred in the same northern European area. These two instruments followed a somewhat parallel course, developing their respective musical styles simultaneously, although bell music was to stay within narrower boundaries. The carillon, then, was one of the early clavier family of instruments that participated in the develop-

ment of instrumental performance as an independent art. Its player, high in the belfry, invariably was the same person who officiated inside at the organ.

A musical development of major significance took place in the fifteenth century: leadership shifted from Italy to the Netherlands—an area encompassing not only what is now Holland but also present-day Belgium and nearby northern France. And it was in this general area, now the most important center of musical art in Europe, that carillon use spread. The intensive involvement with music inside the church was augmented by keen interest in its bells, which had been ringing from the belfry without benefit of human hands.

In this progressive and enlightened corner of Europe the city-states had been especially strong and an influential merchant class of wealthy burghers had grown as the result of a flourishing commerce. There was a general state of prosperity, and cultural pursuits abounded, with ever-expanding interest in learning and the arts, especially in the fields of painting, wood carving, tapestry making, gold and silver working—and music.

During this period all cultural activity had gradually been secularized. The making of bells had long since been removed from the monastery, and bell foundries had been established with their master founders profitably supplying the growing demand for bells, including sets for musical play.

With a populace lured by the enchanting appeal of the bell chime, or *voorslag*, the introduction of the carillon with its human player was but a logical step. Its advantages over the impersonal mechanical ringing were apparent. Once more, as in earlier years when it had been customary to climb the long stairs to the belfry and ring the bells by direct blow, someone was to enter the same loft and extract far more aesthetic value from them—interpretive music.

Unlike the English chiming of a single melodic line, the Flemish and Dutch bell play—human or automatic—was harmonized. The Continental ringing has therefore always

been more elaborate than the English, not only with respect to harmonic texture but in the number of bells used in automatic play. With the introduction of the keyboard, it became the player's task to execute melody and accompaniment—imitating the automatic play—in much the same way that indoor instruments were played.

Today the music of bells is heard intermittently, day and night, in every city and village throughout the Lowlands, adding a romantic aura to the setting of picturesque façades, steep red-tiled roofs, narrow winding streets, and slender baroque spires.

Ten Largest Carillons of North America

Location	Founder	No. of bells	Weight of bourdon (in pounds)	Pitch of bourdon	Instrument pitched in
1) Riverside Church New York City	G and J and Van Bergen	74	40,880	C	G
2) University of Chicago Chicago, Illinois	G and J	72	38,080	C#	Ab
3) University of Michigan Ann Arbor, Michigan	Taylor	53	24,300	Eb	Ab
4) Washington Cathedral Washington, D.C.	Taylor	53	24,000	Eb	Ab
5) Bok Tower Lake Wales, Florida	Taylor	53	22,246	Eb	Ab
6) Peace Tower Ottawa, Canada	G and J	53	22,400	E	A
7) Rainbow Tower Niagara Falls, Ontario	Taylor	55	19,936	E	A
8) Yale University	Taylor	54	13,400	F#	B
9) Thomas Rees Memorial Carillon Springfield, Illinois	P and F	66	14,960	F#	Ab
10) University of Kansas Lawrence, Kansas	Taylor	53	13,750	F#	B

The ten largest carillons in North America are listed above by total weight, not number of bells. (For instance, the carillon at the Kirk-in-the-Hills near Detroit contains seventy-seven bells.) The total weight of bells in these carillons ranges from 37 to 110 tons. Carillons in North America average less than 14 tons, with some as light as 2 tons.

Reproduction of a painting by Walter Shirlaw, The Toning of the Bell. Founder is comparing pitch against a note on the violin.

4 The Musical Bell

THE QUALITY of bell casting and tuning has reached a pinnacle of perfection in recent years only rarely approached in the past. And yet, in spite of technological advances and understanding of the scientific principles involved, bell founding still remains primarily an art. Among the world's craftsmen there is no more exclusive group than the mere handful of bell makers who have realized that today's sophisticated public—less tolerant than its forebears—demands a perfection previously considered unattainable.

The bell founder's task is a complicated one. He must create a homogeneous series of bells of beautiful timbre, and once they are cast, he must accurately tune not only their fundamental frequencies but at least four of their partials. If not overly exposed to the elements, such bells will remain in tune for centuries.

But that is not all. Founders must also be metallurgists,

with an intimate knowledge of the resonating properties of various alloys and the precise proportions of their ingredients—which vary according to bell size. These alloys must be heated to precisely the right temperature (1,050° C to 1,100° C), poured into bell molds, and allowed to cool under very carefully controlled conditions. Too rapid cooling can adversely affect tone and make a bell prone to crack.

Casting a large bell at the Taylor Foundry in Loughborough, England. The workman on the plank is tamping down the molten bronze in the mold.

Today's founder must be familiar not only with the present equal temperament but also with systems of tuning formerly used, since much of his work consists of replacing bells or enlarging sets cast earlier than this century when mean-tone tuning was standard. His diverse knowledge enables him to analyze existing sets and blend the tuning of the new with the old. Timbre must also be matched, and therefore his analysis includes precise measurements of profiles in sets to be enlarged. Besides a bell's geometric proportions, which affect the relative intensities and decay rates of its partials, other factors also bear on timbre: a finely cast symmetrical profile, high-grade alloy in specified proportions with a low percentage of impurities, and a minimum of grinding on the bell's interior wall, which is the means of tuning.

So the musical bell is a veritable work of art, and a whole series, if well matched and of superior timbre, can be considered a masterpiece in craftsmanship comparable in tonal beauty to the best of other musical instruments—and infinitely more expressive than a great many.

The novice can learn bell casting only from an established and experienced founder; generally the skills of the trade are handed down from father to son or to those who have served their apprenticeship under the master founder. Occasionally in the past, the chain of knowledge has been broken or heirs have proved less adept, and many a venerable firm has passed out of existence for this reason.

No scientific literature or technical manuals adequately reveal the secret of the perfect bell. Paul Taylor of the Taylor Bell Foundry in Loughborough, England, states emphatically, "Science is a good servant but a bad mas-

ter." Only the personal touch can create a masterpiece of craftsmanship.

Making a good bell, then, entails not only proper application of physical laws but long years of experience. Each founder has his own tonal preferences, so that his bells have the same individuality found in other fine musical instruments. When listening to bells, the connoisseur evaluates not only their in-tuneness but such qualities as clarity, brilliance, mellowness, tonal warmth, subtlety, depth of resonance, and duration of ring, giving special attention to the extremities of the range.

In this esoteric field, trade secrets are well guarded; they are the founder's most valuable property. None but he—certainly not the theorist—is truly qualified to describe the achievement of a perfect bell; however, even he will say that this ideal still eludes mankind. French founder M. Paccard claims, "The perfect profile of the ideal bell has not yet been discovered by any founder. We have, nevertheless, *twenty* profile types." Thus, a search begun more than a thousand years ago still goes on.

Let's now take a closer look at the type of bell that has been the object of so much interest and examine some of the influences responsible for its strangely magnetic appeal.

Most dictionaries define "bell" as a hollow cup-shaped instrument, usually metallic, which vibrates or gives forth a ringing sound when struck. Although most bells through the ages have indeed been made of metals—of which bronze alloys are foremost—other hard substances have also been found to ring and therefore have been fashioned into bells: glass, clay, wood, and porcelain. In fact, any hard material capable of sustaining vibration and of being formed into a hollow shape can become a bell.

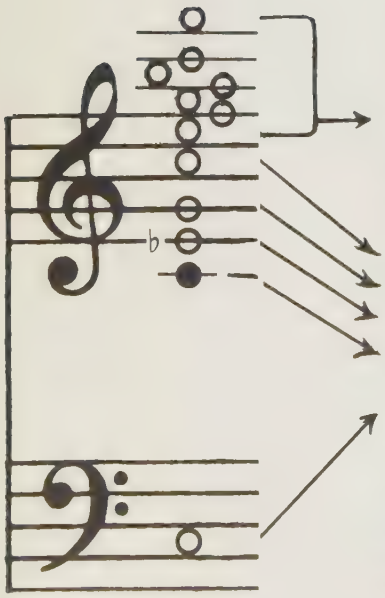
Common to all bells is their hollow form, although not all hollow forms are necessarily bells, of course. A cause of confusion is that sometimes the term "bell" is loosely applied to metal bars, hollow tubes, disks, rods, and other shapes capable of vibrating. Actually, objects of many different shapes may ring and sound *bell-like* without

being bells. From earliest times these have been distinguished from the hollow bell form. Although this form has undergone innumerable modifications for as many reasons, its hollowness has remained a constant factor.

The ring, of course, results from a blow; the bell's tone, like the piano's, is percussive. This blow is always directed near the rim, since it is only by striking here that the full amplitude of vibration is realized. Except for the spherical crotal, all bells have been struck in this way.

The main partials (frequencies of specific pitches) of a well-tuned bell consist of a fundamental (prime), a minor third (tierce), a fifth (quint), an octave (nominal), and a hum tone an octave *below* the fundamental.

The hum tone is the sound that vibrates longest; as it fades into infinity, it seems to hum. Because the hum tone is a frequency below the fundamental, it is sometimes improperly identified as the fundamental itself. However, it can correctly be called the first *partial* of the bell. Medium to large bells also have higher partials of a major tenth and perfect twelfth above the fundamental that contribute to their spectrum of sound and can be tuned. In addition, there is an untuned mass of higher frequencies of relatively short duration.



The partials described above are possible only if the bell is of correct profile, which then must be ground for exact tuning.

Approximate pitches of upper partials. Others are present briefly but have minor effect on the bell's timbre. There is some tuning control of notes E and G.

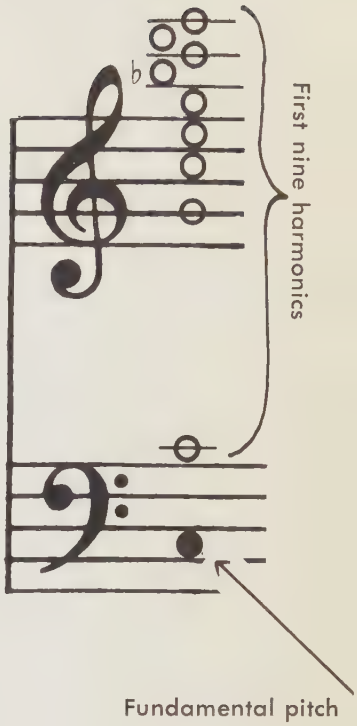
Octave (nominal).

Fifth (quint).

Minor third (tierce).

Fundamental. (Strike-tone is of same pitch but is not a measurable frequency.)

Hum tone (sub-harmonic). Lowest frequency in bell. Some interpret this as the bell's fundamental tone. However, as the dominant pitch is one octave higher, the second partial should be regarded as the identifying or basic tone of the bell.



First nine harmonics of vibrating string. Smaller segments of string produce higher harmonics of diminishing intensity in ascending order.

It should be emphasized that the bell's partials sound in much stronger relation to the fundamental than do those of the vibrating string, although it takes a musically trained ear to distinguish most of them. Prominent is the lingering hum tone of the larger bells, which is easily detected. Furthermore, although the partials of the string are unchanging, those of the bell are in accordance with its contour and therefore not automatically consonant with its fundamental tone. The quest for a more musical bell resulted in its ever-changing profile, and each version produced a new alignment of partials. A climax was reached when the series illustrated at left was found to give the best results. Further improvements in tone quality were still necessary, and have been made from time to time, but the basic partial structure remains unchanged to this day.

Nevertheless, we find that through either ignorance or indifference many founders, especially during the nineteenth century, cast bells with a profile incapable of producing this series. Of course, when the bells were not intended for musical usage—as was the case with the numerous American-made steel bells of the nineteenth and early twentieth century—overtones could be ignored.

Upon impact, a sound called the strike tone dominates momentarily. This has not always been fully comprehended or correctly identified, for unlike the regular partials, it cannot be measured as a specific frequency. We might say it is the first impression reaching the ear upon activation of the combined frequencies at their initial amplitude—a composite effect of specific timbre. Its pitch

should coincide with that of the fundamental, which a moment later comes to the fore and dominates most of the ring.

The partial most essential to a bell's plaintive tone is the minor third; it also happens to be a "problem" interval. When the bell's partials are compared with those of the string (see pages 42 and 43), a basic difference is evident; whereas the first and strongest partials of the string form a *major* triad (C, E, G), those of the bell are tuned to the *minor* triad (C, E♭, G). Although the E♭ is the interval foreign to the natural series, it is nevertheless crucial for establishing the bell's color, and must be present. A major third, if tuned into a bell, would actually make it sound *out* of tune.

It becomes apparent that a bell must have an *inner* tuning—that is, be in tune with itself—before it can be considered a suitable musical member of a series of other pitched bells. Because this inner tuning, or acoustical makeup, differs from the natural properties of the vibrating string or pipe—is of minor rather than major character—the sound of a bell is unique. Its wealth of partials, all blending perfectly, enrich its tone to produce a kaleidoscope of resonance. The bell's magnetic attraction in no small degree derives from this broad tonal texture whose gradual dying away helps to create its peculiar aura of mystery.

But the minor third interval has also been the cause of apparent out-of-tuneness when two bells a major third apart (as C and E) are sounded, because of the resulting discordance between the first partial of the lower bell (E♭) and the fundamental of the upper (E♮), which are a half tone apart. Some carillonneurs avoid this interval as much as possible, and perhaps rightly so on some instruments. However, present-day founders have sought to subdue the intensity of the minor third to a point where its color value remains but the clash of the dissonant interval is reduced to a negligible amount.

The intensity of the higher untuned partials must also be delicately balanced with the tuned, lest the basic tone

be either poorly defined or lacking in richness. Many qualities, then—not all desirable—may be present in a bell, depending on the relationship of the tonal components. It is the founder's responsibility to choose material and so form it as to effect properties he considers desirable—a blend of brilliance and mellowness, resonance and duration of ring, absence of beats, and—not least—perfect intuneness. At the same time, in order to reduce the possibility of cracking, the material must be adequately strong and not excessively brittle. Rather a formidable challenge!

Although from time to time theorists compile useful data on the characteristic functions in bells, computing mathematically what their shapes should be and offering formulas for their material, the founder prefers to rely on his own long experience rather than on such information. This is especially true in the area of timbre and tuning, where he is guided by what he knows will happen, without necessarily asking why.

Ever since the advent of the Bronze Age, bell metal has been a fusion of copper and tin in various proportions, often with a small amount of lead, zinc, and even iron present. These proportions have ranged from approximately 70 percent copper and 30 percent tin (by weight) to as much as 90 percent copper and 10 percent tin.

Most carillon and church bells are made of an alloy of about 80 percent copper and 20 percent tin, although this ratio may be altered according to bell size. Less tin is used in the largest bells (a maximum of 18 percent) and more in the very small ones, which may have a copper-tin ratio of 75–25 percent. In other words, the composition of the alloy and the state of hardness vary according to properties desired for the bell.

The question naturally arises why this particular alloy is most commonly used rather than iron or some other unalloyed metal. The fact is that *no* elementary metal—gold, silver, iron, copper, lead, zinc, and so on—can make a bell of good tonal quality. Bells of silver do not sound silvery, nor do gold bells have a golden tone! Any such metal is too soft. Of course, this is not to say that bells have never

The tuning room of the Whitechapel Bell Foundry, London.

been made of unalloyed metals—the Chinese have even used cast iron—but quality of tone was not a major consideration in such cases.

The property of *hardness*—which implies rigidity and the capacity to "give" and spring back—is essential to ringing. Whether this is found in metal or in other substances—glass, wood, porcelain, or stone—is irrelevant; if it is present, a material will ring, especially when formed into a hollow cup shape. Copper is hardened by adding tin, for example, and the hardness increases according to the amount of tin added. Zinc is added to copper to make brass, but brass bells have a poor sound and lack the strength of those made of bronze.

Clement Attlee, then Prime Minister of Britain, watches the casting of a bell at the famed Whitechapel Foundry in London, England.

A hard metal is brittle and consequently susceptible to cracking. This means that the very property responsible for a bell's resonance and capability of sustained vibration is also its major defect and the reason for breakage. Of all metals, bronze is most suitable as a bell material because of its superior resilience, or elasticity, and its strength. Furthermore, bronze is more durable than iron or steel because it is not subject to rusting—although it does corrode.

In time, corrosion can affect a bell's pitch, and recently a Dutch founder has experimented with a metallic mixture sprayed on old carillon bells to rejuvenate them. It is reported that frequencies were raised, as planned, with only a slight shortening of vibration time. This may prove a means of restoring the original tuning of old bells that are important historically.

Aside from fires and similar man-made holocausts, why do bells crack? Usually it is the very object that makes them speak: the clapper. Repeated blows result in metal fatigue, or a breaking down of the bronze molecules at the point of contact. A weakened area, at first showing no sign of damage, finally opens into a fissure, which invariably extends from the rim upward into the waist.

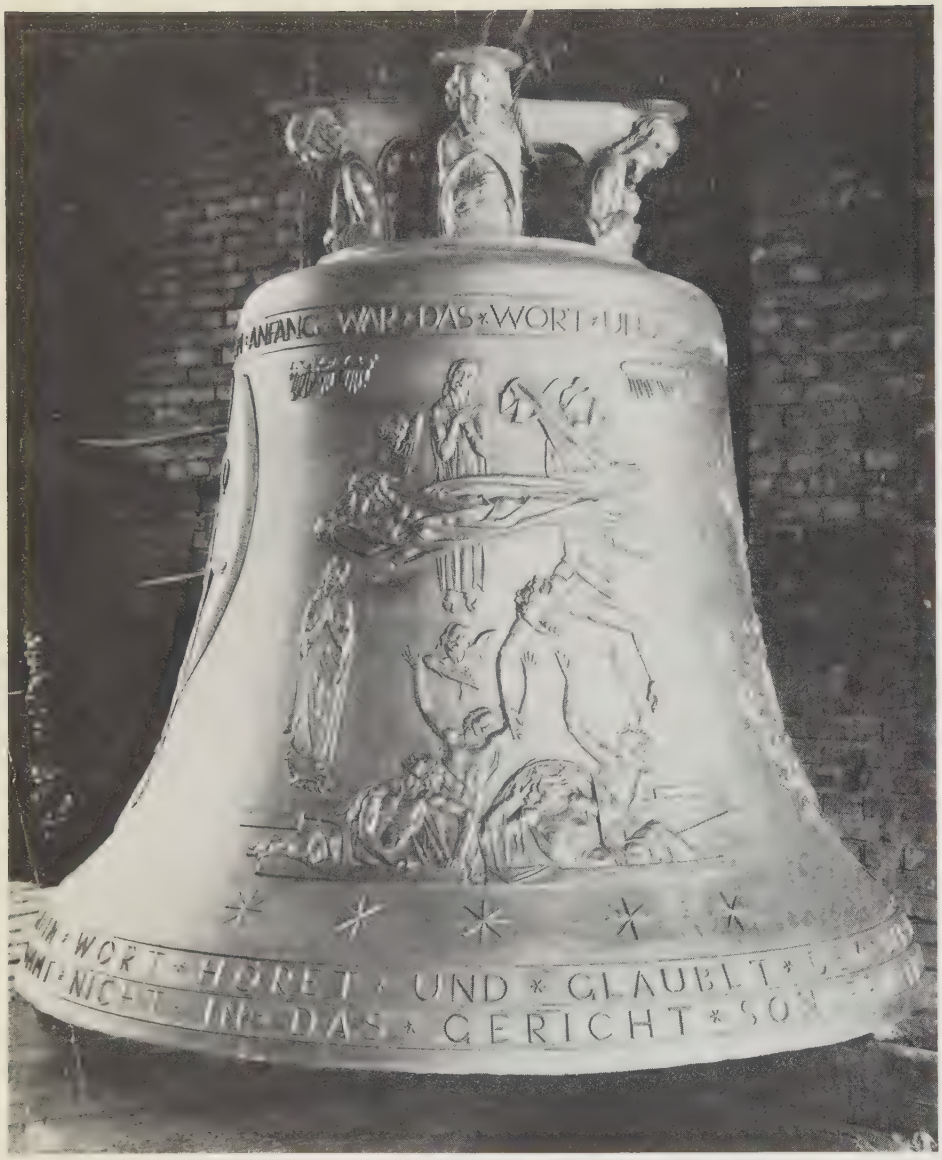
Often cracking is also caused simply by human error. Minute imperfections in the casting may spell disaster for

the finished bell. During the process of pouring, some of the gases can be trapped in the molten mixture. Sometimes the casting is cooled a little too rapidly, setting up a tension in the metal as its outer surface contracts faster than the inner material. Although weaknesses of this kind are not apparent at first, the metal is unable to withstand clapper blows that produce vibrations of high amplitude. It is suspected that this was the reason why the Liberty Bell first cracked.

Then, too, there can be fatal miscalculation in judging the right proportion of tin, which results in an overly brittle bell. Therefore large bells that must sustain heavy blows contain less tin than smaller ones, which are thicker in proportion to size. The copper-tin ratio is vital to a bell's overall quality, in terms not only of durability but of resonance, duration of ring, and timbre itself. There are no set rules, however, and the exact composition of bell metal is governed by the personal preference of the individual founder.

A final cause of cracking is simply too powerful a clapper blow for the bell's wall to withstand. It can occur especially with swinging bells, because the clapper traverses the entire inside distance, wall to wall, gaining enough momentum to deliver a much harder blow than a clapper moving only a few inches.

No tower bells cast before the twelfth century remain in use today in Europe. There are a number of reasons. Some of the earlier ones cracked and had to be removed, but often old bells were replaced by others that were larger and better toned. This was especially true as tuning techniques improved. Frequently the new bell was a recasting of the old one, thus limiting our knowledge of the original to perhaps a written description or a drawing of dubious reliability. A common fate also was removal as a trophy of war. Then, too, after the introduction of gunpowder, bells were frequently melted down to make cannons—becoming instruments of destruction against the very people they once had served.



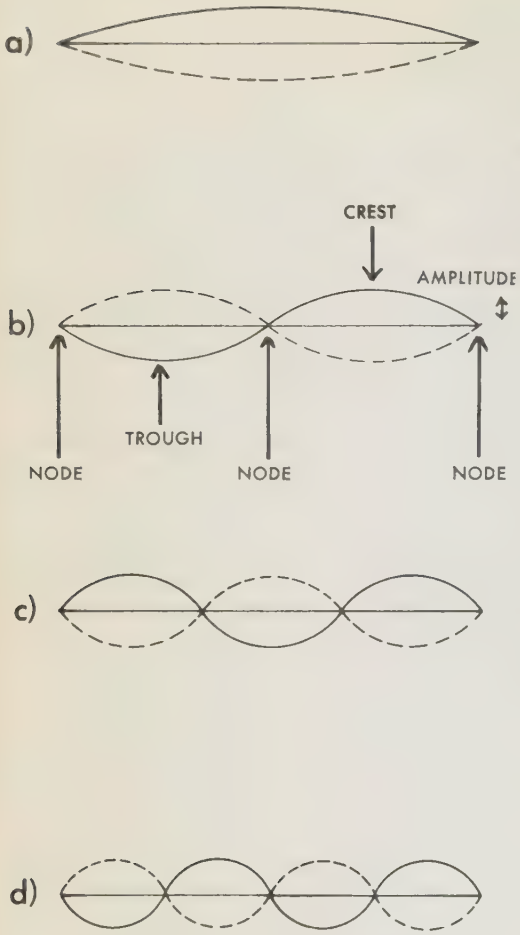
Bourdon Bell at Meissen Cathedral, Saxony, Germany, is one of Europe's most beautifully decorated bells. It was designed by Paul Börner of the Meissen Porcelain Factory.

Assorted bells at the Petit ar
Fritsen Foundry, lying on the flo
ready for shipment.

5 The Acoustics of Bells

THE BELL is more complex acoustically than any other vibrating body intended for musical purposes, and its manufacture presents a formidable challenge. Its very campaniform nature produces an array of frequencies which, if not controlled, would prevent any harmonious blending of tone when two or more bells are heard simultaneously. Consequently, proportions must be determined that will result in frequencies and their amplitudes considered desirable in a musical bell.

There are four basic means of activating musical sound: striking, blowing, rubbing (friction), and plucking. Today we might also include electronically produced sound. The two most common media of musical sound itself are the vibrating string (plucked, struck, or bowed) and the hollow tube or pipe (blown), with or without reed. Other sound media are struck solid objects—wooden, stone, or



The first four partials of the taut string. In addition to oscillations of the whole, which produce the fundamental tone, the string divides into segments (2, 3, 4, 5, etc.), each of whose frequencies is a multiple of the fundamental frequency. These vibrating segments produce the series of harmonics.

In figure B, a complete wavelength is represented by the solid line. Its amplitude is the distance from the position of equilibrium. The points at the center and ends, called nodes, have no movement. The vibratory movement is an alternation of the solid and dotted lines.

metal slabs, tubes, disks, gongs, and bells. These are classified as idiophones—naturally sonorous bodies. Membranous objects also produce sound when struck, such as the tambourine and the various kinds of drums.

In none of these—with the exception of the bell and, in part, the metal bar—can the pitch of partials be regulated, since the partials are in fixed relationship to the fundamental tone, harmoniously or otherwise. However, in many instances there are ways to modify their intensities. Thus, although tone quality can be controlled in all musical instruments regardless of type, the bell is unique in that not only is this done, but the frequencies of its important partials must—and fortunately can—be adjusted to bring them into a musical relationship with one another. As we have seen, this relationship differs from the natural harmonic series of the vibrating string or pipe.

Now, before going on to discuss precisely what happens when a bell is struck, let's first examine the nature of vibration and how musical sound is produced.

Sound is a form of energy given off by a vibrating body. For example, if a taut string is displaced from its position of equilibrium—whether by plucking, striking, or bowing—waves are generated in the string. The length of the most important wave, forming the fundamental tone, is equivalent to twice the string's length. The string also divides into segments—producing correspondingly shorter waves—whose lengths are simple fractions, 1/2, 1/3, 1/4, 1/5, and so on, of its total length.* Their rate of vibration increases in inverse relation to length; in other words, the two halves vibrate twice as fast as the whole, the thirds three times as fast, quarters four times, and so on. Each segment is sep-

*Laboratory experiments have shown that although frequencies of the first six or seven partials adhere to a strict harmonious relationship to the fundamental, the higher ones become increasingly sharp as the vibrating segments become shorter, and thus are inharmonious in increasing degree. The bell's upper partials likewise are inharmonious.

arated by a point of rest, called a node, from which displacement on opposite sides is in opposite directions.

The more pronounced the displacement—amplitude of the wave—the more intense the sound. Differences in amplitude have no effect on the rate of vibration; if this were not true, music as we know it would be impossible, since every change in dynamic intensity would result in a change in pitch!

The string's tautness—or tension—makes vibrations possible. Once a displacement has been effected, creating waves of given frequency and amplitude, oscillations continue until the waves' energy is gradually dissipated, through internal and external forces. Stretching a string more taut does not change the wavelength of either the fundamental or its partials, but it does increase their frequency (cycles per second) and thus raises pitch. This is because more force is needed to draw the string from equilibrium—the displacement meets with more resistance—whereupon it springs back more rapidly, resulting in oscillations of greater velocity.

A violin is tuned by turning pegs to regulate string tension. The player then further changes pitch by pressing his fingers at appropriate points, shortening the string, in effect. In the first instance, the greater tension (assuming the string was tightened) increases rigidity, thus raising pitch, whereas shortening with the finger reduces the wavelength, automatically increasing the rate of vibration, or pitch. In this case, the string's tension remains constant, but the shortened wavelength vibrates at a corresponding increase in frequency. If the finger exactly bisects the string, the vibrating portion sounds one octave higher than the open string, with a frequency precisely double.

The string's density and its diameter also have a bearing on the frequency of vibration. The former varies according to the material of which the string is made; thus, two strings of equal diameter and under equal tension, but made of different materials—gut and steel—vibrate at different rates. Greater density, resulting in more inertia,

The Nieuwe Kerk (New Church) at Delft, the Netherlands.

tends to decrease rate or vibration; a larger diameter, likewise increasing inertia, has precisely the same effect.

There are two basic types of sound waves—transverse and longitudinal. In the transverse wave, the particles of the vibrating material—as those of the string—move at right angles to the direction of the wave's motion, that is, up and down, perpendicular to the string itself. The wavelength is measured from crest to crest, or trough to trough (see page 50).

On the other hand, the motion of a longitudinal wave is back and forth, in a direction parallel to the wave's propagation. This movement causes alternate areas of compression and rarefaction in the vibrating medium—a bunching together and spreading apart of the particles—which may be a gas (such as the air), a liquid, or a solid. The medium must have density and be flexible in order to be capable of sustaining vibration; sound cannot travel through a vacuum. The source of longitudinal movement may be a body vibrating transversely and agitating the air from its quiescent state, first producing an area of compression, which immediately rebounds to one of rarefaction. Both appear to move forward in regular succession through the medium to produce an advancing wave. The distance from one area of rarefaction to the next, or one area of compression to the next, is the length of one wave.

The pitch of a sound is determined by the frequency of the successive waves or vibrations—for instance, the number of oscillations occurring at a given point per second (cycles per second). The speed of sound varies according to the medium through which it passes. Thus, it travels faster through water than through air, faster through metal than through water, and faster through steel than through bronze.

The velocity of sound in a given medium is not affected by pitch, since its measure is the wavelength multiplied by cycles per second. This is expressed: $V = WL \times CPS$. Consequently, since longer wavelengths vibrate proportionately more slowly than shorter ones, in a given interval

of time *all* will reach the ear at the same instant. When listening to music, imagine the chaos if higher notes reached the ear ahead of lower ones! It follows that a sound's intensity does not pertain to its velocity.

Our previous reference to a fundamental tone and its natural harmonics, and to amplitude, leads to a final property of sound that is basic to music—timbre, or tone quality. Timbre is governed by the *number, relative intensity,* and *distribution* of the partials in a tone source. Incidentally, these need not be the natural harmonics of the vibrating string or pipe. The difference between musical sound and mere noise is that the first consists of a uniform series of sound waves, originating from a combination of partials in mathematical relationship (exact multiples), and the second is an irregular series whose source contains a mixture of unrelated (discordant) partials.

Overtones—or, more specifically, the most prominent ones—must therefore be concordant in musical sound, and their frequencies must remain constant (pitch-wise) for its duration. We can identify sustained tones of equal loudness—for example, those of a string, organ pipe, or woodwind—because of the arrangement of their harmonics, different combinations of which sound with more intensity; in each case, some are substantially suppressed whereas others dominate the spectrum.

A single tone source, such as a musical note, sends through the air a combination of different wavelengths that form a single one of irregular shape. This results from the interaction of the component partials according to their individual amplitudes. Thus, the ear detects differences in timbre by the type—that is, the shape—of wave reaching it. In the case of the vibrating string of the piano or violin, the sounding board and resonating chamber are responsible for this shaping, effected by the intensification of certain partials.

Thus, it is apparent that a musical tone is a composite of many components whose pitches cover a considerable span from the fundamental upward, and without which the tone

would be colorless. For example, the tone of the tuning fork is largely a single harmonic one; in contrast, that of the bell is perhaps richer in harmonic content than any other, and the relative loudness of its partials to fundamental is far greater than in other important musical tone sources.

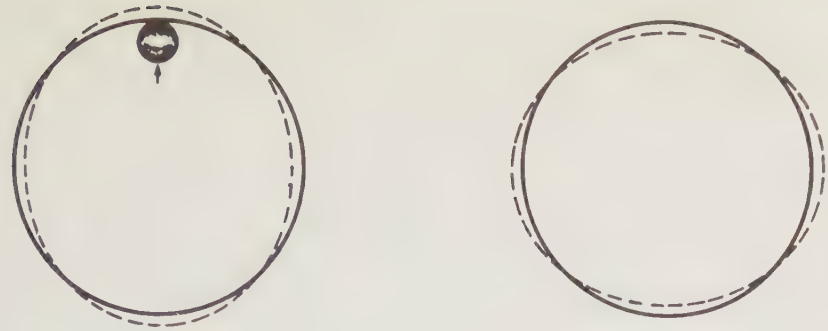
How do these principles apply to the musical bell, singly and in series? The character of the bell's sound is determined by *how* it vibrates and *what* vibrates. The clapper strikes the bell near the rim, at the thickest part of the sound bow, a region where maximum elastic movement and resonance occur. The great number of sound frequencies produced by its ringing are each associated with characteristic modes of vibration contained within the bell. These modes are defined by lines on which radial motion (motion to and fro from the bell's axis) is nil at the characteristic frequency. Such *nodal* lines of quiescence are found both *vertically* around the bell (called meridians) and *horizontally* at different elevations (called parallels).

This radial movement gives rise to another, known as *tangential* motion, which is a compression-expansion oscillation of the particles of the bell wall; it is complementary to the radial motion and the logical result of its deformations. However, since the acoustical radiation—that is, the sound—is almost entirely caused by the radial vibration, the tangential motion is not relevant to this discussion.

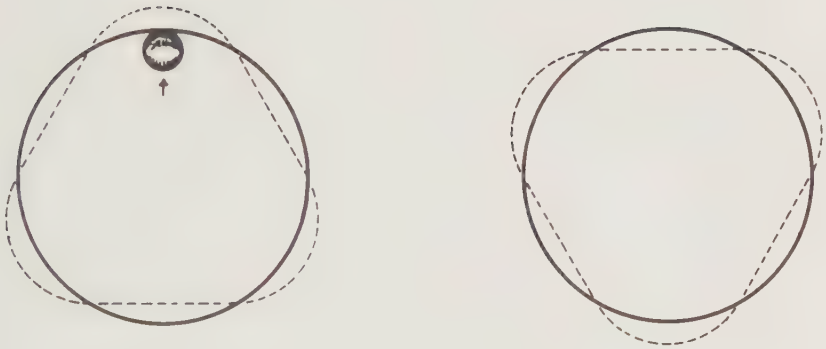
Let's imagine a bell cut in half vertically and a thin slice removed from the cut edge. This slice would roughly resemble a tuning fork and would vibrate in a similar manner. The tuning fork's prongs vibrate laterally from the stem where they are joined, having a node (point of no movement) near the base. The fork can also have other nodal regions, or lines, along its prongs which are associated with higher frequencies, or partials. But in a tuning fork, the loudness of the partials is purposely subdued, whereas in the bell the cross-sectional design is such as to *enhance* them, thus imparting musical qualities to the bell.

The bell may be considered as a series of thin vertical

On the outline of a bell's circumference are shown nodal divisions (where broken lines intersect) of the important partials, or positions of vertical meridians:



Two wavelengths:
- Hum tone
- Fundamental
- First fourth above the nom



Three wavelengths:
- Minor third
- Fifth
- Second fourth above the nominal

Four wavelengths:
- Nominal and other higher tuned partials

Whereas the position of the bell's horizontal parallels derives from its contour, the meridians are positioned according to place of strike.

slices bound together. When struck by the clapper, the bell's wall is forced out of the round into a near-elliptic shape. In effect, the distortion sets the small cross-sectional pieces into vibration. In the region of impact, they are forced outward, while one-quarter around the bell's periphery from the point of strike the motion responds inwardly. The elastic rebound then forces it into a near-ellipse at right angles to the first. The continued alternation of these two patterns produces the fundamental pitch and hum tone. This type of motion results in four points—nodes—on the circumference which do not move radially from the bell's axis.

These four equidistant vertical nodes, extending from lip to head—the lines of quiescence, or meridians, previously mentioned—are positioned according to the spot where the clapper strikes.

Since the bell's initial deformation is not a pure ellipse, other nodal meridians are produced as well. These divisions are also associated with various partials—both tuned and untuned—in the bell. It has been determined that the vibrating segments producing the partials of the minor third and the fifth are separated by six nodal meridians forming three wavelengths; those producing the nominal (octave of the fundamental) are separated by eight meridians forming four wavelengths. Higher frequencies contain various equidistant nodal divisions—numbering 6, 8, 10, and 12—which coincide in part with the four basic nodal lines (see page 55).

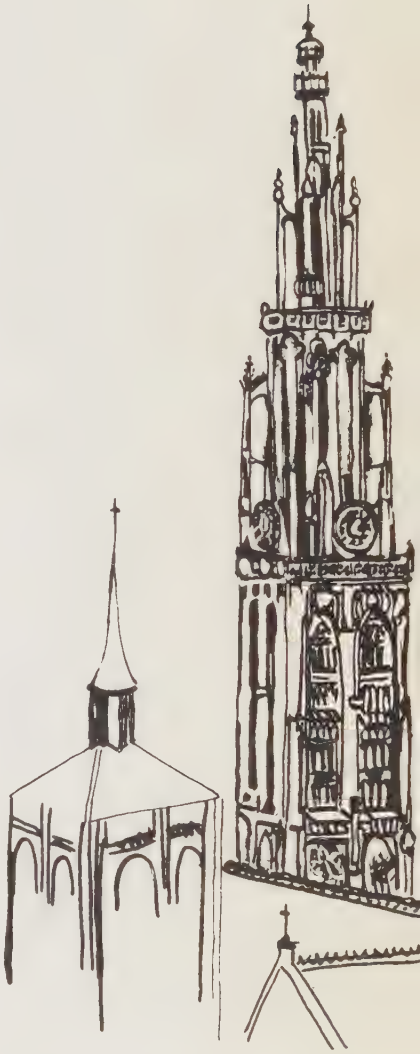
Let's again use the flexural vibrations of the tuning fork for comparison. The radial movement of the bell wall emanates from a nodal head at the top of the bell; this is similar to the fork's stem. Oscillations from this main node toward the rim—with the single exception of those producing the lowest partial, or hum tone, which has only this node—are divided by *horizontal* nodal lines around the bell's circumference; these are the parallels, mentioned previously, whose position depends on the natural vibration patterns resulting from the bell's geometric form (see

pages 58 and 59). Therefore, unlike the tuning fork, the bell wall's characteristic contour causes a multiplicity of wavelengths and frequencies. The whole is a homogeneous mass, all of whose modes of vibration are interrelated and interacting.

The fundamental and nominal vibrate in the region directly above the rim (see page 60). The hum tone, on the other hand, sounds throughout the bell (excluding its four *vertical* nodal lines) and, like the two octaves above, is loudest at the rim. The minor third is located above the sound bow, adjacent to the fundamental, in a rather narrow area around the bell where wall thickness begins tapering off. And finally the fifth appears above this, at midwaist, and continues into the head. The wall is thinnest here and the resonance is a good deal less than lower down; this partial is therefore the least important of the tuned ones.

The profile is responsible for modes of vibration that determine not only the frequencies of various partials but also their intensities. The lower area that terminates at the lip, being more flexible and having more mass of metal, emits the strongest ring; thus, this is the most important vibrating portion of the bell. During the first moment after impact, the three octaves—nominal, fundamental, and hum tone—establish the basic pitch, but other partials, tuned and untuned, contribute significantly to timbre. Except in the smaller bells, the nominal is initially strong at impact but decays much more rapidly than the first three partials; in fact, *the intensity relationship of all components changes as a function of time.* The bell is not unique in this respect, since it has been demonstrated that the same phenomenon occurs in the vibrating string.

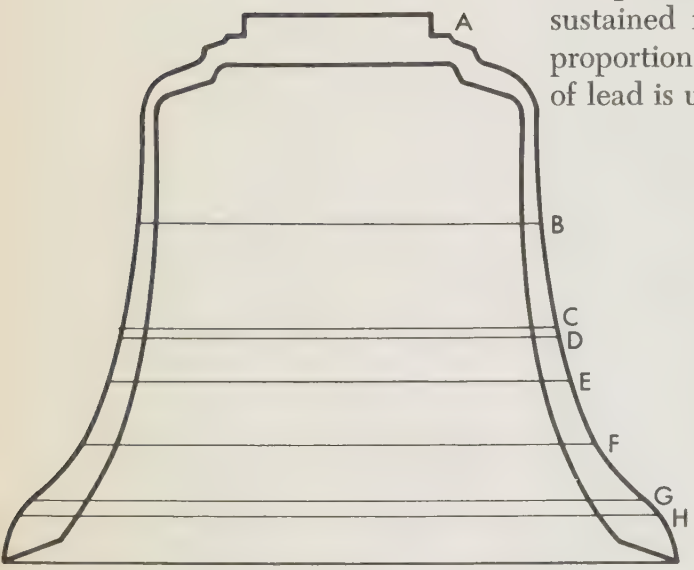
Tonal decay results from loss of elastic energy as it passes into heat (internal damping of the metal) and from radiation of acoustical energy (external or acoustical damping). In other words, the natural rigidity of the material acts to arrest the vibratory movement, and so does the resistance of the surrounding air and consequent friction.



The bell tower of Antwerp Cathedral in Antwerp, Belgium.

The effect of friction becomes apparent when a bell is placed in a vacuum, where its vibrations are sustained for a much longer time.

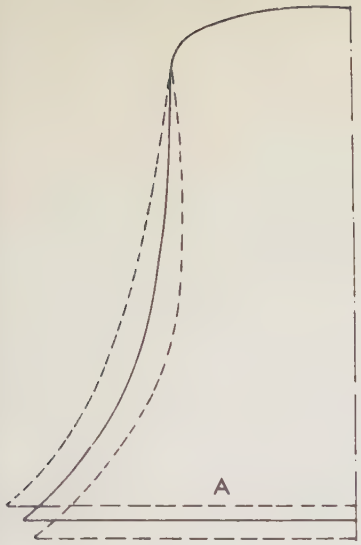
The rate of a bell's tonal decay is an important measure of its worthiness. Three factors are involved: material, size, and profile. The material must be sufficiently hard for a sustained ring; in bronze, this hardness depends on the proportion of tin, as we have seen. More than one percent of lead is undesirable in bell metal, not only because of its

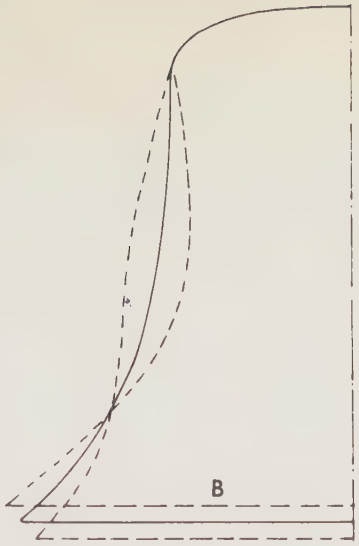


Horizontal lines B to H show approximate positions of nodal parallels of vertical vibrations that produce bell's important partials. The hum tone (lowest frequency) has only one node, the head.
A: Head of bell is node for all vertical vibrations, including hum tone.
B, E, and G: Higher (untuned) partials.
C and G: First and second fourth above nominal.
D: Octave and fifth above nominal; nominal; minor third.
F: Fundamental.
H: Major third and seventh above nominal; fifth.

adverse effect on tone—especially its duration—but because it weakens the alloy.

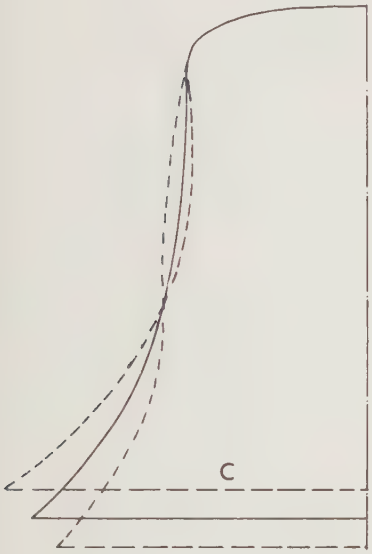
Obviously, larger masses of metal are capable of more acoustical energy, other factors being equal, and will vibrate longer. Therefore, no effort is made to equalize either resonance or duration of ring from one end of a series of bells to the other; indeed, there is no reason to do so. The piano's resonance is similar, with the greater amount in the bass. However, this does not imply that in a sequence of bells *tonal balance* is not present, for there must be a uniform progression from the full-toned basses to adequately resonant trebles. This requires careful attention to profile dimension and to graduation of weight. The well-matched set is devoid of any irregularities in timbre from bell to bell.

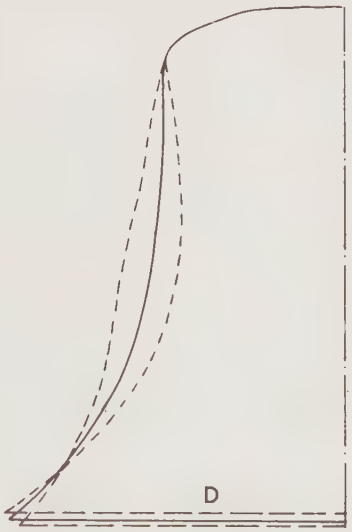




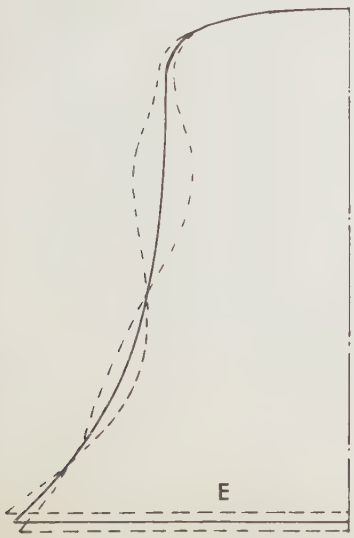
Diagrams of important vertical vibrations in a carillon bell of a given profile. Its geometric shape, size, and wall thickness are responsible for wavelengths of various frequencies. The most pronounced frequencies are in simple mathematical relationship to the fundamental.

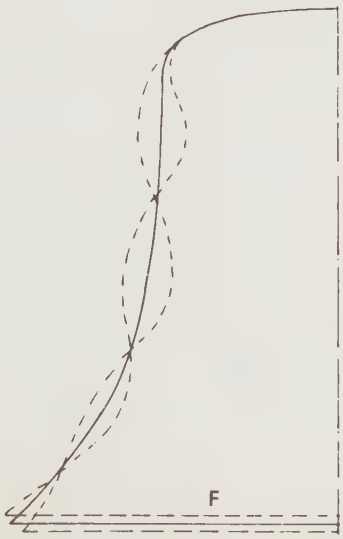
A: Hum tone.
B: Fundamental.





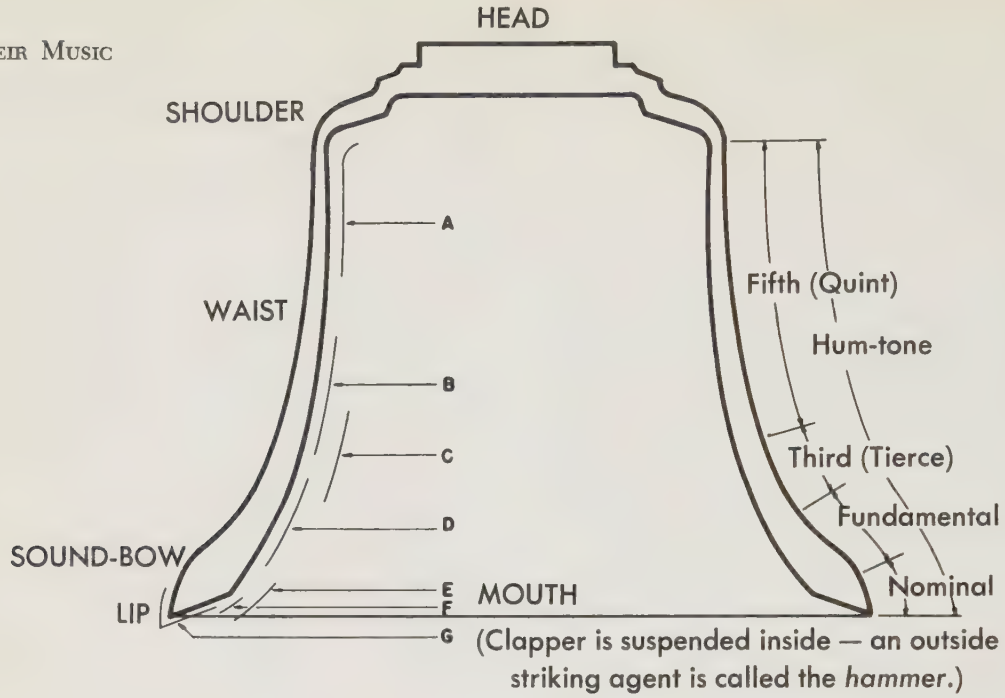
C: Minor third; nominal; fifth and octave above the nominal.
D: Fifth; major third and seventh above the nominal.





E: First and second fourth above the nominal.
F: Other high (untuned) partials.

fastening to wooden beams. Most bells nowadays are without crowns, and are bolted directly to beams).



Positions of partials are indicated at right in outline of bell above. A to G at left indicates areas of bell wall where grinding affects partial frequencies. Grinding at A flattens fundamental and hum tone; at B flattens quint; at C flattens tierce and nominal; at D flattens fundamental; at E sharpens fundamental; at F flattens nominal; at G sharpens nominal (and fundamental somewhat) by reducing height.

Tonal decay is most rapid immediately following impact and then levels off as the vibrational energy is dissipated. Bell partials, then, fade at different rates, with higher frequencies dampening more rapidly than lower ones; in the final moments of the ring, the hum tone becomes more evident. Because of this changing relationship, the bell's tone during decay undergoes a subtle and continuing transformation—a performance, moreover, which varies according to the size and profile of the individual bell. Especially do the relatively rigid walls of the upper trebles cause quick fading of any higher frequencies present; indeed, their signal is inconsequential. The fundamental,

hum tone, and minor third are dominant in these upper trebles, but the nominal—which in larger bells is strong at impact—makes only slight contribution to their sound. Furthermore, because of the weakness of the trebles' higher partials, the strike tone, so pronounced in larger bells, diminishes with the ascending scale until its characteristic quality disappears from the ring. Since higher frequencies result from smaller vibrating portions of the bell wall, it is not surprising that their movement is quickly overcome by the wall's rigidity. The brilliance of the lower and middle range gives way to a simpler but clear tone in the treble, whose relative lack of significant upper partials keeps it a purer harmonic sound. On the other hand, bells in descending order grow richer in harmonic content, with duration of all partials increasing and the hum tone assuming a more important role.

We can conclude that relative initial strengths of partials in different-sized bells, as well as the decay patterns, vary appreciably except for the general tendency of all higher partials to fade more quickly than lower ones.

The exact nature of the strike tone—the sound heard at the instant of impact—has been the subject of much speculation and study. Some have suspected that it is a "difference tone," or one resulting from the nominal and fifth above, whereas others have defined its pitch as being fixed an octave below the nominal. Because of its brief duration, analysis of the strike tone has been difficult, which accounts for its elusiveness. Everyone agrees, however, that this initial sound is sharper and richer than the fundamental partial of similar pitch that dominates immediately thereafter.

Modern electronic equipment has made it possible to examine graphically what seems to take place during that first fleeting instant of impact. A tonal spectrum of the first second and a half of two successive strokes on a bell was made recently with a Sonagraph by two French physicists, Castellengo and Leipp, at the Laboratoire d'Acoustique de la Faculté des Sciences de Paris.

Shortening the prongs of a tuning fork raises its pitch. If the prongs are thinned by filing at A, pitch would also be raised. Attaching weights at the tips lowers pitch through increased inertia, but if weights are lowered on prongs, pitch is raised.

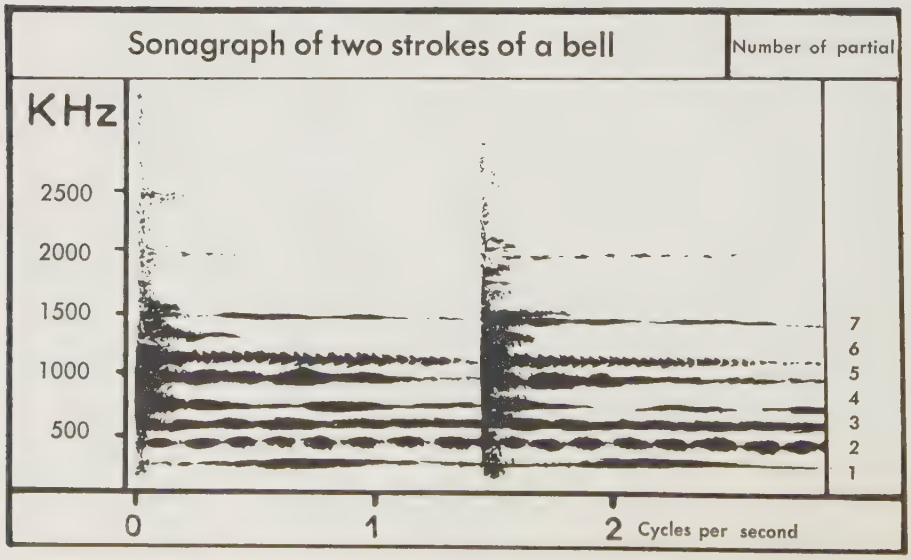
Thinning at B lowers pitch by weakening the area, but if thinning is continued farther up it would raise pitch again, although not to the level before grinding. Thus, thinning the entire length lowers pitch.

C is fork's nodal point. However, the transverse movement of the prongs results in longitudinal vibration of the stem. While a bell's modes of vibration are more complex because of its contour and the changing thickness of wall, the results of modifying the tuning fork are similar to modifying the bell wall.

From this representation (graph at bottom of page) let's see what is happening: The strike tone contains frequencies spanning 3,000 cycles, in which the greatest intensity generated is shown to be from the third to the seventh partial. Of these, the fifth appears to be dominant for half a second or so. But why this initial "blob"?

The logical explanation is that the impact of clapper on bell is of such force as to initially create a temporary distortion. At that precise moment the normal patterns of vibration have not yet fully formed, and a momentary asymmetry occurs from the blow's force until all parts have had time to establish regular vibrational patterns. Thus, their homogeneity is not immediate. The result is that for a fleeting moment a wide spectrum of frequencies appears, all in continuous succession and without individual selectivity. The total effect is a sudden impulse of maximum intensity and brilliance, followed immediately by a more orderly series of frequencies as radial motions normalize.

The strike tone therefore is an essential and identifying characteristic of a bell's ring, resulting from the initial deformations of the wall at the earliest stage of vibration. Almost immediately—within one-fifth of a second in the bell—the dominant fifth partial gives way to the second and third.

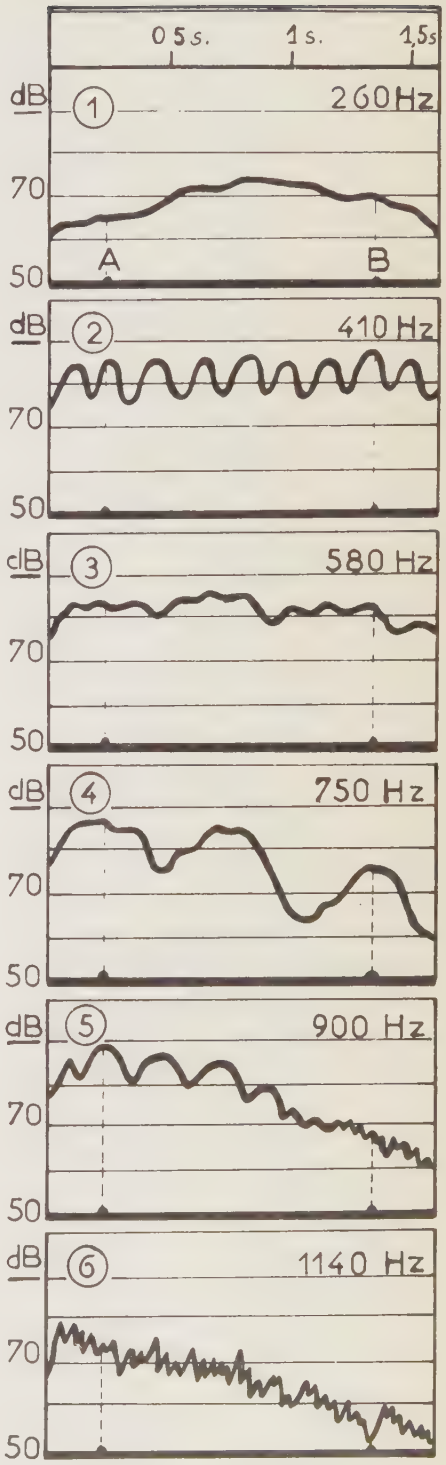


Using another graph (right), the performance of the first six partials following the stroke was shown more clearly according to their decay function. Certain behavior patterns were evident which conform to what is known about a bell's ring, according to other methods of analysis. Partials four, five, and six showed rapid decay, whereas two and three were relatively uniform except for the pronounced beat in two. The hum tone rose somewhat in intensity before starting to fall off. (Partials in the string behave in somewhat similar fashion.)

At the foundry a bell mold is carefully prepared to conform to a shape deemed best suited to the quality of tone and tuning desired. Normally the casting comes out of the mold intentionally pitched a little sharp, so that frequencies can be brought into exact tune, chiefly by flattening. This is done by grinding metal from the inner surface, in areas known by the tuner to affect individual partials. Only small amounts can be removed; if it seems necessary to grind off more in order to secure a certain frequency, then it becomes apparent that the profile is wrong, and the bell must be recast. Any irregularities of contour spoil the tone.

Thinning the bell's wall by grinding decreases the mass and the metal's rigidity and has the same effect as loosening a violin string—a lowering of pitch. Consequently, grinding in the upper portion of the waist produces more flexibility toward the rim and reduces the vibration rate of the fundamental and hum tone. Thinning directly below this area flattens the fifth, and further below, the third. Removing metal from the lip, which reduces the vertical dimension slightly, has a sharpening effect. Grinding in the area of the sound bow is another way to lower the pitch of the fundamental (see page 60).

But in actual practice the process of tuning is far more complex than this brief account would indicate. Frequen-



The graph right shows more precise decay behavior of the first six partials in same bell as in graph on facing page. Each partial is identified by the number in the circle. The three fractions across the top refer to the time intervals in seconds: *0.5s*=½, *1s*=1, and *1.5s*=1½. To the left, outside the frames, *dB* indicates decibel scale (measure of loudness). The number in the upper right corner of each frame indicates the cycles per second *(Hz)*.

cies are so interrelated that none can be considered an individual entity; the regulation of one will also affect another, and not necessarily in the same direction. Therefore the total result must be constantly observed during tuning, lest in bringing one frequency into line another is knocked out of tune. Incidentally, this operation may require only an hour or so for small bells, but up to a week for the larger ones.

The essential difference, then, between the tuning of a string and the tuning of a bell is that the string is tightened to increase tension and pitch—tuned up—whereas the bell is loosened, so to speak—tuned down.

The tower bell is commonly described as tulip-shaped because of its general resemblance to the flower. A glance at its profile (page 58) shows a gradually increasing thickness of the wall, starting at the top and reaching a climax at the sound bow, then rapidly decreasing until the terminal point of maximum diameter, called the lip. The inner and outer walls are similar in contour, except for the formation of the sound bow by a graceful bulge of the outer wall. If we draw an imaginary line down through the center of the wall, a uniform curve is evident, at first moving slightly away from the bell's axis and then at an increasing rate as it approaches the lip. Both diameter and wall thickness increase from top to bottom; one is proportional to the other.

The contour of the English handbell's wall (page 65) follows this basic form very closely. Two important differences, however, are the absence of a sound bow and a proportionately thinner wall of uniform thickness. Such a contour greatly simplifies the vibrational pattern, and the two dominant partials of the handbell—those tuned—are its fundamental and a twelfth.

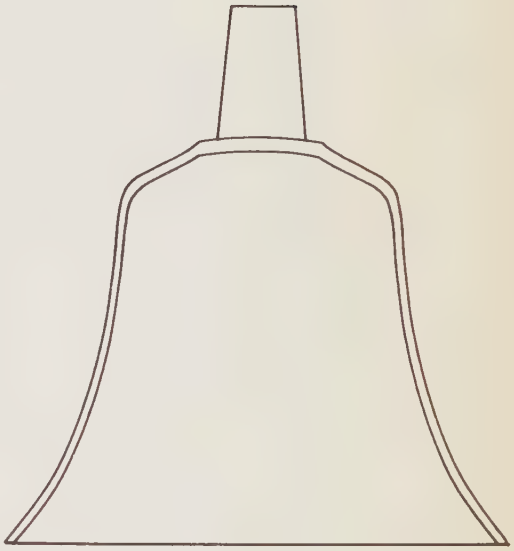
The significance of wall thickness to pitch is clearly shown in a comparison between a carillon bell and a handbell of identical pitch. If its pitch is middle C, the carillon bell's diameter is about 60 inches and its weight 4,700 pounds, in contrast to the handbell's diameter of 6-5/8

inches and weight of slightly more than 3 pounds. In the carillon bell the ratio of wall thickness (at the sound bow) to diameter is approximately 1 to 13-1/2 or 14, whereas in the handbell it is 1 to 70! We should add, however, that this is a comparison between the *second* partial of the carillon bell (fundamental tone) and the *first* of the handbell, which has no hum tone.

In all bells, enlarging the diameter lowers pitch, while a corresponding increase in thickness (and consequent rigidity) raises it. Hence, by delicately balancing this relationship, a profile is achieved that is capable not only of the desired frequencies but of determining their intensities and duration. *An adequate thickness of the sound bow is especially important.* Variations in contour detail are also relevant in carillon bells, that is, the degree of waist concavity and the angular or curved shaping of the sound bow—factors that do not affect basic dimensions (see page 68). Such differences can be seen in the products of various founders and help to identify each, visually as well as acoustically.

Occasionally the ring of a bell will be uneven, containing beats, or pulsations—periodic rises and falls in intensity. This is caused by a lack of symmetry in casting, a result of irregularities in thickness and in the composition or homogeneity of the metal. If molten metal is cooled too rapidly, it tends to be excessively porous, which lowers the rate of vibration. Ornamentation on a bell can also result in asymmetry. Even a minutely thicker area will vibrate at a frequency slightly different from that of a corresponding undecorated portion of the wall. The rate of the resulting beat depends on the distance between the two frequencies; it slows up the closer they are together, and would disappear should they coincide. Few bells, in fact, are perfectly symmetrical.

One founder has recently introduced a technique for correcting any lack of symmetry; slight amounts of metal are removed from the bell's inner surface by making small grooves at selected points. In effect, this compensates for



Profile of English handbell. Although its wall is relatively thinner than that of a tower bell, its basic proportions are almost identical.

irregularities by "evening up" the bell, restoring its symmetry. Overall tuning is not affected.

Large bells, weighing four tons or more, are often subject to a special hazard. This is the appearance of an unwanted partial of the perfect fourth above the fundamental, which was not actually tuned into the bell but is present nevertheless. Sometimes its intensity is enough to almost dominate the ring. It is still not clearly understood why this occurs, because the interval cannot be traced to a specific cause. Even though two bells have identical profiles, one may possess this fourth whereas the other does not. Furthermore, as this profile may have the same relative proportions as smaller bells (without the fourth), it would seem that the fault has nothing to do with the shape. Some claim that it results from too thin a wall, but if this were so it should be present in all thin-walled bells—which is not the case. One founder, Hein Fritsen, believes it is not a fault of profile but of the metal itself. He states that the alloy is probably responsible and finds that limiting the amount of tin to 18 percent or less is beneficial. The homogeneity of the casting also favors an even and full tone with a strong nominal but no fourth. However, a majority of bells weighing ten tons or more have this interval to some degree, although its sound is not necessarily unpleasant.

The problem of creating good ringing trebles has long occupied founders, but real success has been achieved only recently. There was probably less pressure in the past to perfect this area, since musical requirements were more modest then than they are today. Sets of five octaves, and upward, now appear occasionally, ranging from a bourdon of twelve or more tons to a top treble of about twenty pounds. In such circumstances, a thin upper register would have limited musical value.

Balancing these trebles tonally has been accomplished by strategically altering the profile, whereby overall size and wall thickness are proportionately increased. At the same time, the hardness of the metal is altered by adding

more tin—approximately 25 percent—which not only improves the ring but raises pitch. Let's see why this is so.

Every solid body—as well as liquid or gas—has a certain degree of elastic tension which, together with its density, determines the velocity of longitudinal vibrations running through it. This is expressed as $V = \sqrt{E/D}$, in which V represents the velocity of longitudinal waves (in effect, the speed of sound through the material), E is Young's Modulus, or elastic tension in a solid, and D is the density value (mass per unit of volume). Using this formula, the speed of sound in a given solid is obtained as a figure equal to the square root of a quantity found by dividing Young's Modulus E by the density of the mass. Therefore, the longitudinal vibrations in bell metal are proportional to the square root of the metal's elastic tension and inversely proportional to the square root of its density. All other modes of vibration in the material are correspondingly proportional to the longitudinal rate.

What all of this means, simply, is that inasmuch as the density of bronze is very little affected by the quantity of tin, an increase in tin, which heightens the elastic tension or rigidity of the material, speeds its vibration rate, in much the way that tightening a string raises its pitch. Thus, if two bells of equal size contain different proportions of tin, the one having the larger amount will be higher pitched. The greater hardness also prolongs the ring.

Founders more or less adhere to certain general dimensions, allowing for some latitude in diameter and weight for a given pitch, as well as for details of profile. For example, in the lower and middle range, proportions are approximately as follows: the top diameter is 57 percent that of the bottom; height to the top plate is 80 to 85 percent of the base diameter; thickness at the sound bow is 1/13 to 1/14 of the greater diameter. These relationships do not entirely hold true in the treble. In past centuries, ranges were limited to three or three and a half octaves because of various difficulties encountered at either end.

Bell tower of town hall at Veere, the Netherlands.

Typical profiles of tower bells: A: Flemish and Dutch. B: English. C: French, Italian, and Spanish. D: German and Russian.

Barriers at the low extremity were of a technical nature related to the great weights involved, and four tons were about maximum. Of course, cost was also a factor. The Hemonys' heaviest bell, a low A, weighed this amount, and their lightest, an E, about 33 pounds.

The problems of tuning and securing a good ring in the upper treble have been formidable. Since the tuning fork was not invented until 1711, founders before then were severely handicapped. The Hemonys' tuned rods were less effective in tuning small bells than they were for large ones. Nevertheless, their results were amazing, comparing favorably with the best today. But they were less successful in perfecting their trebles. In common with other early founders, they tried to improve resonance by enlarging the profile, but the tone still remained somewhat thin and quick-decaying. The ineffectiveness of the treble range was further aggravated by the considerable height of most European bell towers; the sound simply dissipated in the atmosphere.

Founders today, besides being able to tune with greater precision than ever before by using adjustable tuning forks and electronic equipment, have contributed greatly to carillon art by improving the tonal qualities of the trebles. They have done this by changing the relationships between the physical factors of size, weight, profile and wall thickness, as well as the components of the material itself. To compensate for the rigidity of a thicker wall, which might hinder ring, a harder but more resilient material is used. Even dimensions have been altered, although not consistently among founders. Some increase the height in proportion to diameter, while others reduce it and, at the same time, increase the upper diameter. Again, this demonstrates that bell making is an art with individual judgment overriding the laboratory formula.

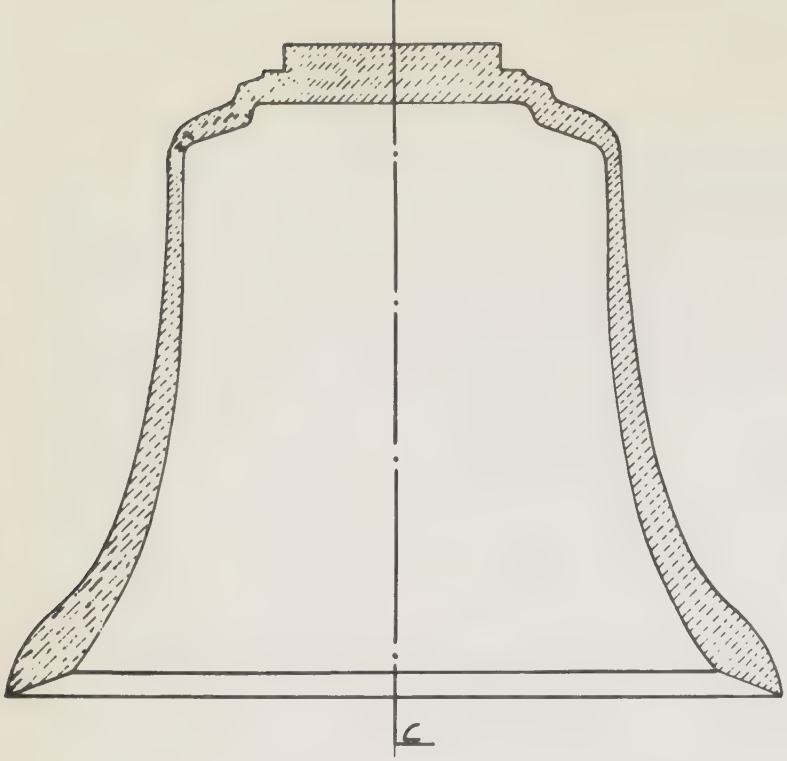
Not only is it necessary to consider the musicality of a single bell, but its relationship to others must also be taken into account. Before casting a set of bells, the founder lays out their profiles on the drawing board, scaling diameters

and other dimensions to achieve uniformity of tone from note to note (see page 102). Weight, diameter, and pitch are closely related, but in ever-changing ratio. Most founders are prepared to cast both "light" and "heavy" profiles as circumstances require. Swinging bells, for example, fall in the latter category because of the harder blow they sustain. This is especially true with bells used in English change ringing, where it is desirable that all the bells of the peal be of equal resonance. Therefore the decrease in their weight in ascending order is less than in corresponding carillon bells (see page 103). Profiles of a series are also in accordance with the initial bell whose weight and tonal character determine the upward scaling.

The diameter of a bell—or, more specifically, its radius—governs pitch, just as does the length of a string or pipe, by determining wavelength. However, the bell and string differ in one respect: whereas the string's length is equal to half the wavelength of its fundamental, the bell's circumference encompasses *two* wavelengths of the equivalent frequency. Doubling its diameter decreases pitch one octave, assuming the material (alloy) and profile do not change (see pages 70–71). Pitch is thus inversely proportional to diameter.

In the lower register, a rule of thumb is that on descending a major third, weight doubles, and multiplies by more than eight when the distance is an octave. Moving upward, the diameter ratio of 2:1 for the octave interval gradually narrows as bells become proportionately larger in relation to their lower octave. The table on page 78 shows a typical departure from this ratio, and it is evident that without such adjustment bell sizes in the upper treble would be entirely inadequate.

Weight scale can be modified at both extremes of the range. If diameters in the bass are made to exceed the 2:1 (octave) ratio, that is, if the diameter of the lower bell is a little more than twice that of its octave, the potential effect is a lowering of pitch beyond the desired level. However, a corresponding increase in thickness acts to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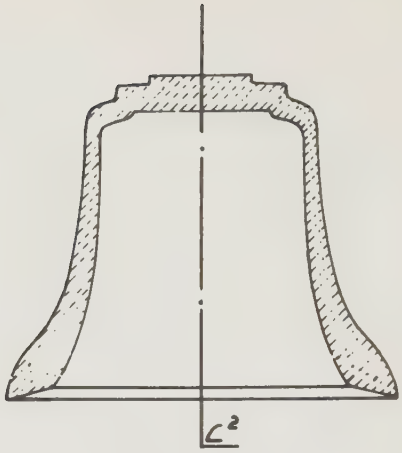
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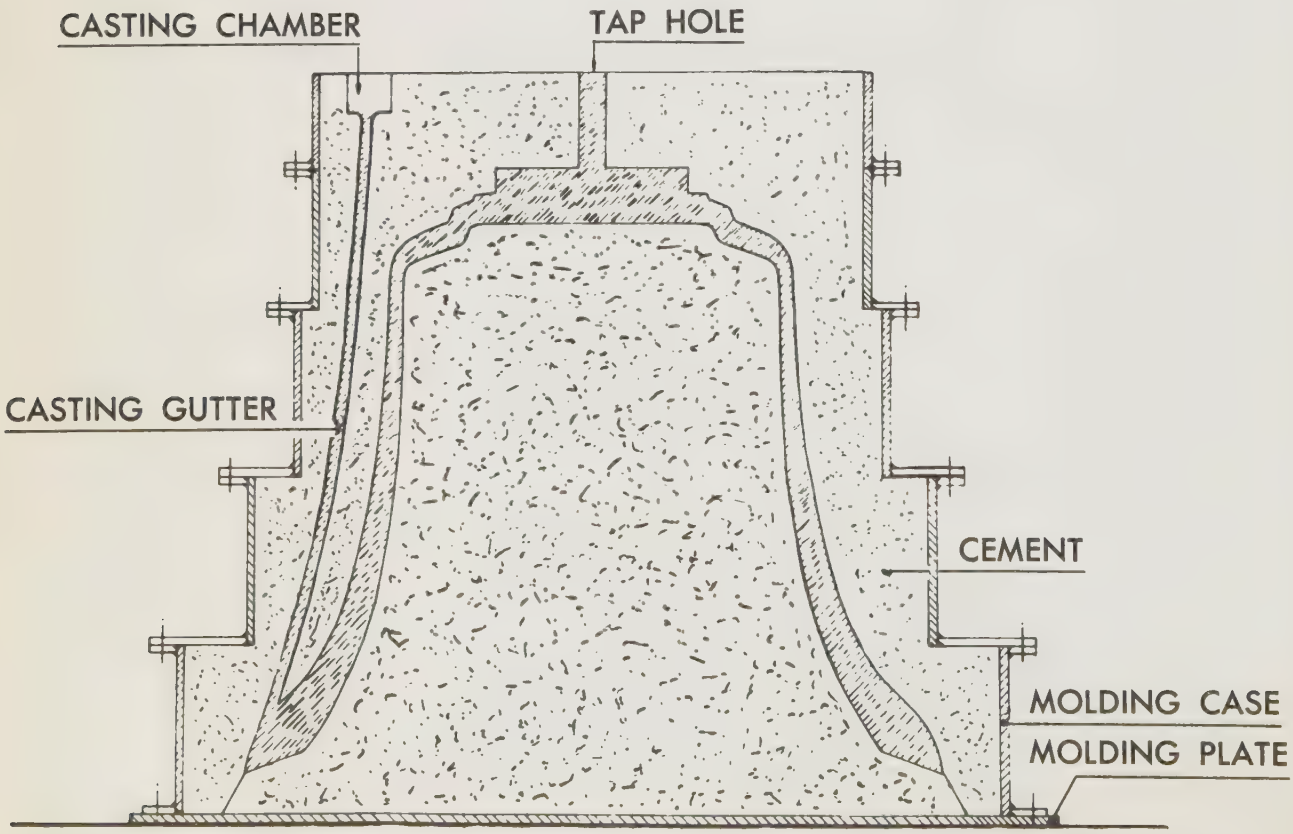
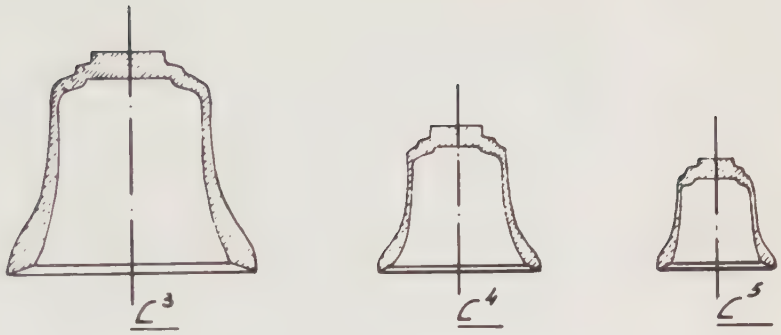
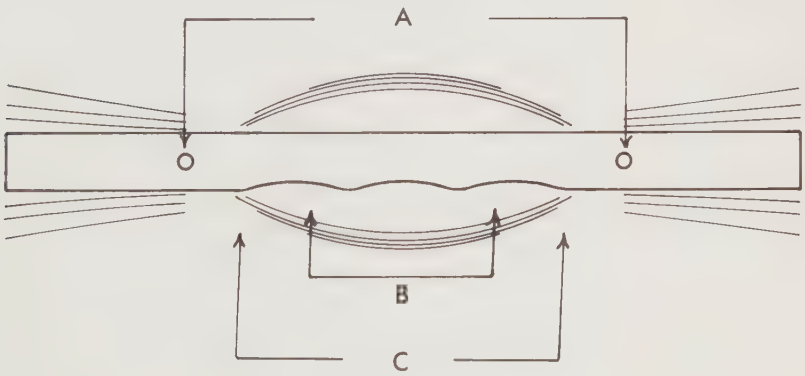

CASTING CHAMBER
TAP HOLE
CASTING GUTTER
CEMENT
MOLDING CASE
MOLDING PLATE



Above, the relative sizes of five profiles of bells from pitch middle C upward through four octaves. In the upper register, modification of profile (especially by thickening the wall) and an increase in tin content permit a departure from an otherwise 2:1 diameter ratio for the octave.

At left is a bell mold. Molten bronze is poured in at the left and tamped down through the hole in top center. The inner mold is called the core: the outer the cope. Fabrication of molds differs with the individual founders.



Shown here, for comparison to the bell's acoustical complexity, is the chief mode of vibration of the tuned metal bar such as is used in vibraphones. The fundamental pitch and a harmonic two octaves higher are tuned by grinding in the middle area. The bar is suspended on cords running through holes positioned at nodal points.

restore it. This produces the "heavy" profile, yielding a bell of deeper resonance and more powerful tone. But in the trebles, as diameters depart from this multiple, the ratio of wall thickness to diameter increases in far greater proportion, which results in a bell substantially heavier for its size. Consequently, the octave (weight) ratio of more than 8:1 in the bass area narrows, until it becomes less than 2:1 at the top. A relatively small degree of change occurs, both in diameter and weight, in the sequence of bells from C4 to C6; reduction in diameter from note to note approximates 3 percent or less, in contrast to 15 or 16 percent at the other end (see table on page 76).

Because of the vast amount of metal required in the first two octaves, it is obvious that this part of a set accounts for the greatest cost. In fact, the bells of a complete five-octave carillon, starting on middle C, weigh less than a single bell one octave lower!

Reference throughout has been to bronze bells. Let's see how steel compares to bronze as a bell metal. Although steel bells are considered less desirable than those of bronze, it is interesting that of two similarly pitched bells, the one of steel is capable of more initial brilliance and loudness than the bronze one. The reason for this is that since steel has greater elastic tension (hardness), longitudinal waves—and hence all modes of vibration—are of higher frequency than in bronze. Therefore, if a steel bell were of the same profile as one of bronze, it would require a diameter larger by almost one-half and a weight more than two and a half times greater to equal the bronze bell's pitch. A much greater mass of steel has to be set into vibration to produce the same pitch. If bells of the two metals were of equal size, the steel one would sound about half an octave higher.

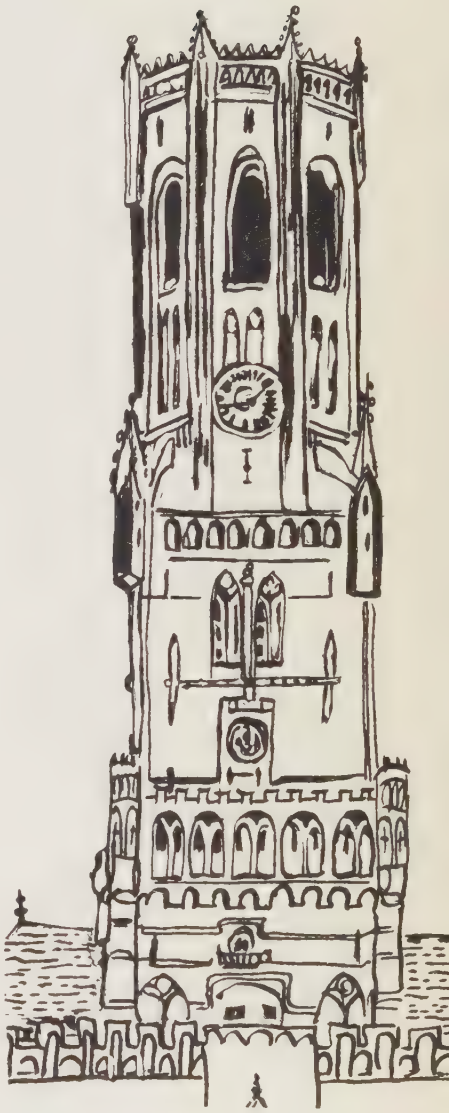
The necessary diameter for a specified pitch was achieved in the nineteenth-century American steel bell at the expense of its other dimensions. Page 78 shows the greatly exaggerated mouth with wall sharply tapering inward; height and upper diameter are proportionately less

than in the typical bronze bell. Curiously enough, in America's early days steel bells were sold according to diameter rather than weight; consequently, bell makers drastically reduced the quantity of metal—and therefore their own expense—by shrinking the body of the bell! Today any of these bells that remain have little value, except as sentimental mementos.

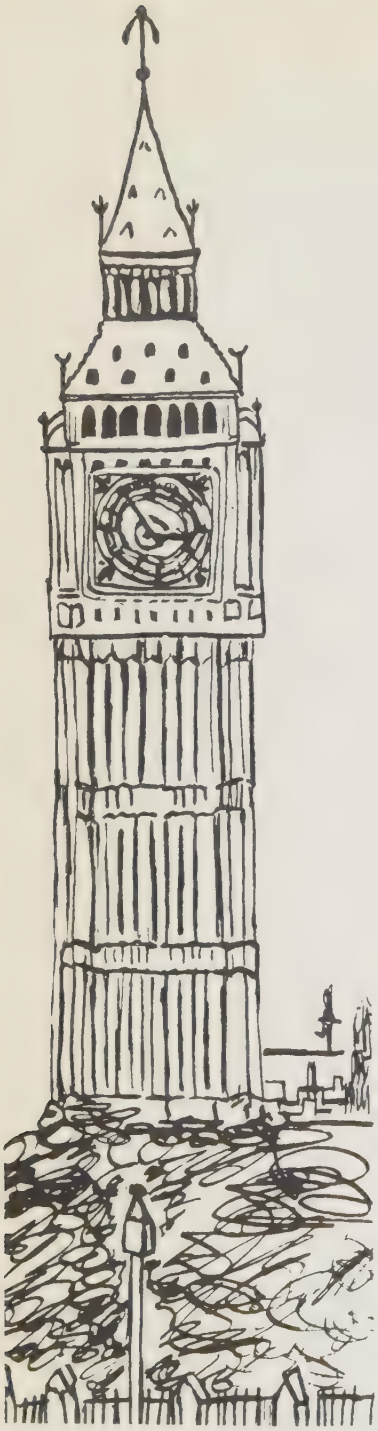
If a steel bell has the same contour as one of bronze, its partial structure is the same—the material itself is not relevant. The chief difference in the tone of a steel bell is the initial sharpness, after which vibrations become rapidly dampened. In short, its ring is poor.

Because of the directional nature of the sound radiation of a bell's partials, their respective intensities are heard in varying degrees, depending on the listener's relative position. The bell's geometric shape is responsible for this fact. Thus, two people standing in different places will not hear quite the same quality of sound. The same effect is produced by the swinging bell, whose sound is heard from ever-changing angles in rapid succession, each of which slightly alters the balance of the tonal components reaching the ear. Hence, its characteristic "ding-dong" sound. Also contributing to this sound shift is another factor, called the Doppler effect; when rapid movement brings the ear closer to a sound source, a slightly higher pitch is heard, while movement away has the opposite result. Since bells are usually heard out-of-doors, and often when one is riding in a vehicle, the rapid change of relative positions creates the sensation that the pitch and tonal quality of the bells vacillate. The same Doppler effect is apparent when listening to a fast-moving train or airplane approach and pass.

Of course, the distance between ear and bell determines how loudly it will be heard. The intensity of a sound wave is inversely proportional to the square of the distance from the source. Thus, a person 500 feet away will hear an intensity only one-twenty-fifth as great as someone only 100 feet away (1×1 over 5×5). This ignores any possible



Bell tower of town hall at Bruges, Belgium.



Bell tower of Houses of Parliament, London, England. The hours are tolled by 15-ton Big Ben, whose sound is better known than any other bell in the world.

deviations caused by reflections or absorptions in the area, or wind factors, which might alter the result. On the other hand, excessive proximity augments the sound to an uncomfortable degree. At 50 feet, for example, the intensity is four times greater than at 100 feet, and *100 times* greater than at 500 feet.

Carillon audiences are usually widely dispersed and consequently receive totally different impressions of the bells' musical effect. Ordinarily, the most satisfactory position is somewhere between 200 and 400 feet from the instrument. The carillon's elevation above ground level is also important, especially if the bells are sizable. Depending on the surrounding terrain, as well as the proximity and height of neighboring buildings, this elevation may be from 60 to 250 feet.

The material, size, shape, and weight of the bell's clapper also influence the quality of sound. The metal must be neither too soft nor too hard. Too soft a clapper produces a dull tone lacking in clarity, and the rounded surface of the clapper itself tends to flatten where it strikes the bell, thus enlarging the area of contact. Too hard a clapper gives a harsh tone because of the predominance of the higher partials; it also causes the formation of a pocket in the bell wall. Regardless of which material wears first—clapper or bell wall—too much surface area comes into contact for a clean blow. Cast iron is the most common clapper material, although one founder uses a special kind of manganese bronze with highly satisfactory results.

Clapper weight must also be considered. This varies with the founder; Petit & Fritsen, for example, uses a formula whereby the thickness of the sound bow multiplied by 2.4 gives the diameter of the clapper ball. As the ratio of wall thickness to diameter increases in the treble, so does the ratio of clapper weight to bell size. (In any given bell, the weight of an outside hammer is about half that of the inside clapper.) If too light, a clapper will fail to bring the mass of metal into full vibration and all frequencies will not be activated. It must also strike at the correct point on the sound bow or the balance of the

partials' intensities will be upset; even slight deviations in pitch may be observed, depending on the point of striking. Needless to say, too heavy a clapper not only produces tonal distortion but can fatally damage the bell. Like a rubber band that breaks if stretched too far, the bell metal's flexibility also has a limit—its point of yield. If the bell is subjected to too severe a blow, its vibrational movement is forced beyond that point, and it cracks.

The founder makes certain that the clapper will swing in a direction exactly perpendicular to the area of striking, with its center of gravity correctly aligned to achieve maximum impact and prevent any friction caused by an oblique contact. It is also important that it clear the bell immediately lest the slightest lingering dampen the bell's vibration. This requires a mechanical precision throughout the working parts—from key to clapper suspension—and fine adjustment of the action. When the carillon player depresses a key, it must not hold the clapper against the bell. It has been demonstrated, however, that even the most staccato blow is of multiple character. During the clapper's brief moment of contact, the vibrating bell repeatedly beats upon it!

Besides the physical factors of size, profile, and material, there is still another influence on pitch: the temperature of the metal. A rise in temperature causes it to expand, enlarging the bell slightly and correspondingly decreasing the rate of vibration. But since all partials, irrespective of a bell's size, are proportionately affected, relative values are unchanged, and consequently no out-of-tuneness results.

People who notice apparent differences in the sound of certain bells from time to time are, in truth, responding to changes in the acoustical conditions, such as the presence or absence of noise in the area at different times of day, atmospheric changes, the amount of vegetation nearby, the presence of snow or rain, and so on. The tone of the bell itself is unchanging.

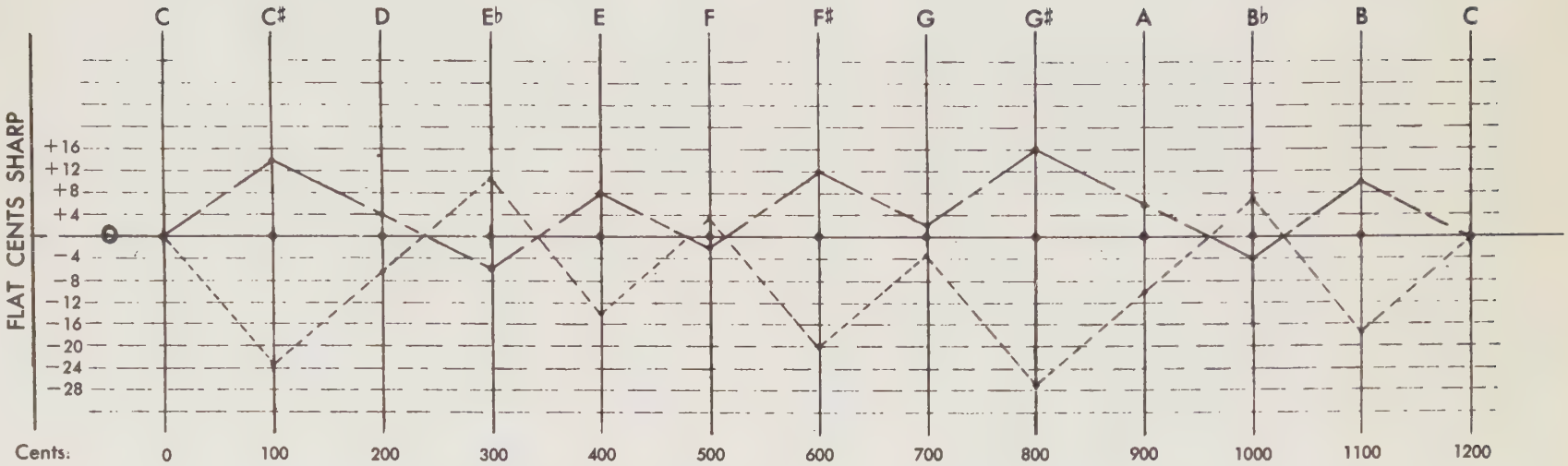
Table of Comparative Tunings

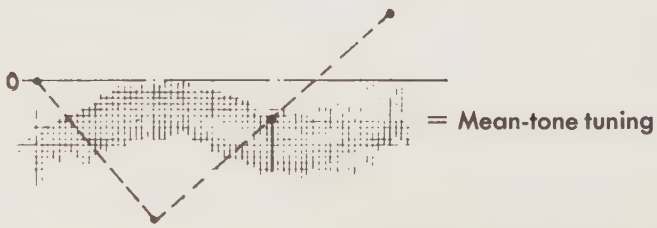
Four basic systems of tuning have been applied to bells since the ninth century. The earliest was the *Pythagorean,* which remained in use until the sixteenth century. *Mean-tone temperament* was customary for most carillon bells until the present century; now it is largely superseded by *equal temperament. Just intonation* is still employed in England for church bells heard diatonically, as in change ringing. In this table all intervals are expressed in cents, according to the four historical systems, with some fractions rounded off.

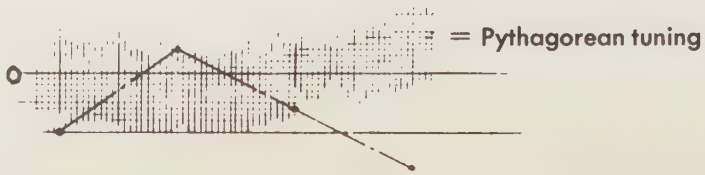
Interval	Pythagorean	Just Intonation[1]	Frequency Ratio	Mean Tone[3]	Equal Temperament[6]
Chromatic semitone (as C to C#)	114	92 or 70	19:18 or 25:24	$75\frac{1}{2}$[4] (sharp by $\frac{1}{4}$ comma)	100 (sharp)
Diatonic semitone (as C to Db)	90	112	16:15	$117\frac{1}{2}$ (sharp by $\frac{1}{4}$ comma)	100 (flat)
Whole tone (major-second)	204 (pure)	204[2] or 182 (92+112) (70+112)	9:8 or 10:9	193[5] (mean tone)	200 (flat or sharp, depending on ratio)
Minor-third	294 (flat by a Syntonic comma)	316	6:5	$310\frac{1}{2}$ (flat by $\frac{1}{4}$ comma)	300 (flat by 16 cents)
Major-third	408 (sharp by a Syntonic comma)	386	5:4	386 (pure)	400 (sharp by 14 cents)
Fourth	498 (pure)	498	4:3	$503\frac{1}{2}$ (sharp by $\frac{1}{4}$ comma)	500 (sharp)
Fifth	702 (pure)	702	3:2	$696\frac{1}{2}$ (flat by $\frac{1}{4}$ comma)	700 (flat by 2 cents)
Minor-sixth	792	814	8:5	814 (pure)	800 (flat)
Major-sixth	906	884	5:3	$889\frac{1}{2}$ (sharp by $\frac{1}{4}$ comma)	900 (sharp)
Octave	1200	1200	2:1	1200 (pure)	1200 (pure)

1. All intervals listed in just intonation are pure. The syntonic comma (81:80), or an interval of 22 cents, is the amount of variance of the "wolf" intervals from the pure. 2. Major tone or minor tone. 3. There were also various modifications of mean-tone temperament, an indication of the continuing interest by theorists in formulating more satisfactory tunings. 4. Note the difference of 42 cents between the chromatic and the diatonic semitones, or the differences between C♯ and D♭. 5. The mean-tone interval of the second is a mean between 204 and 182. 6. All intervals are multiples of the 100-cent semitone.

Diagram of Historic Tunings of Bells





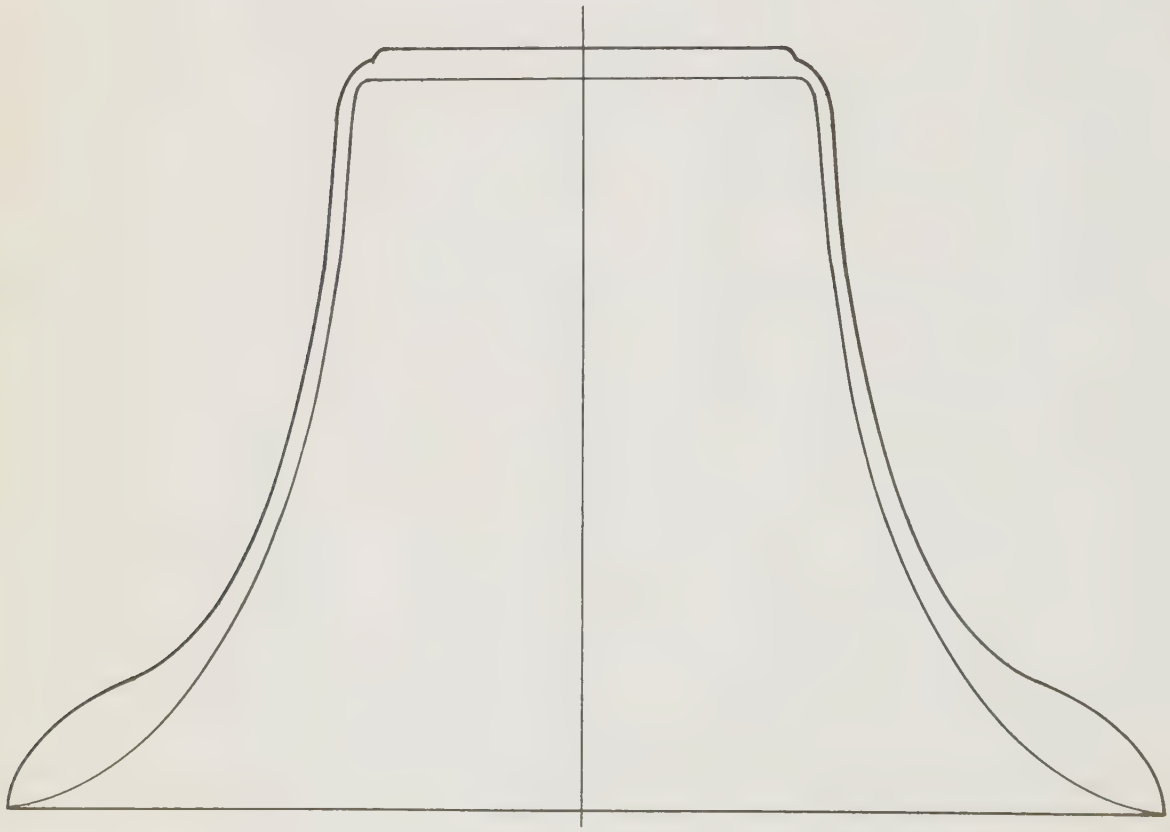


A diagram of three important historical tunings of bells since medieval times, showing the respective positions (in cents) of their intervals. In equal temperament, all intervals are multiples of 100 cents. To read the other tunings, add or subtract the appropriate number of cents. For example, the size of the interval C to E♭ (minor third) in mean tone temperament is found by adding 10½ to 300; the same interval in Pythagorean tuning is read as 300 minus 6, or 294 cents. Carillon bells today, with few exceptions, are tuned in equal temperament. (See table of comparative tunings on facing page.)

Table of Bell Diameters of Ascending Octaves

	Bell diameters of ascending octaves (in inches)		*Approximate weight (in pounds)*	*Diameter if halved*
Maximum practical range for tuned bells	C^0	120	40,000	120
	C^1 (middle C)	60	4,700	60
	C^2	30	600	30
	C^3	17	125	15
	C^4	10½	40	7½
	C^5	8	24	3¾
	C^6	5½	18½	1⅞

Area of enlarged profile



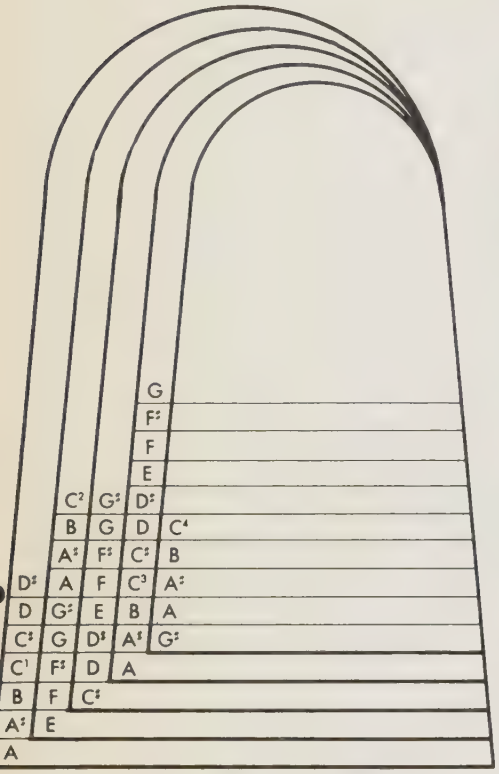
Profile of typical cast steel bell of nineteenth and early twentieth century in America. The exaggerated lower diameter attained the desired pitch, but the small waist greatly cut down the amount of metal required.

Tuned porcelain bells now in the belfry of the Frauenkirche, Meissen, East Germany. They are shown with Paul Börner, who made them in 1929.

6 Other Ringing Materials

BELLS, over the years, have been made from a number of materials besides metal. It is essential only that the substance be hard and capable of vibration. Of all the nonmetallic materials used for ringing, two have had some success musically—stone and porcelain.

Wooden bells, or other hollow wooden forms, have existed in many parts of the world, although sometimes the distinction between the wooden bell and rattle has been slight. But the percussive use of wood rather surprisingly has had a widespread association with religious practice. Large wooden bells have been substituted for metal ones in some Japanese Shinto shrines. In the Fiji Islands wooden gongs called *lalis* have been carved from trunks of trees. And for more than 2,000 years the Chinese have fashioned ornamental fishes from camphor wood which is hollowed out; inside is a loose wooden pellet which rattles about when the fish is struck with a wooden stick. The



Profiles of tuned porcelain bells, made at the famed porcelain factory in Meissen, Germany. There are five basic sizes, in graduated lengths to produce a range from A below middle C upward three and a third octaves. A wooden felt-covered hammer strikes (by automatic action) on the outside at the relative elevation indicated. Maximum possible height for a porcelain bell is about 20 inches.

fish, having no eyelids, is the traditional symbol of wakeful attention, and its wooden image resounds during prayers in both Buddhist and Taoist temples, besides being used for signaling purposes in monasteries.

Not a bell, though producing a ring of considerable resonance when struck with a heavy mallet, is the hanging or sacred board of ancient Asiatic origin. Its Greek name, *semanterion,* meaning signal, identifies its function. Such boards hang in Chinese monasteries, where they may sound the curfew or summon the inmates on special occasions. In the Buddhist monasteries of Japan they serve as a summons to prayer.

These percussive boards also have a long European history, beginning with the Greeks and spreading to other areas occupied by the Orthodox Church—the Balkan countries, the Ukraine, and so forth. They may in fact have preceded church bells in much of Eastern Europe, especially in its more isolated sections. While such boards do not appear to have spread west, various types of large wooden rattles have been widely used in Spain, Portugal, and Italy—even England—to summon worshipers, particularly during the period in Holy Week when the ringing of bells in the Catholic Church is forbidden. The *semanterion* is still common today in Greece and Yugoslavia.

Although stone is impractical as a material for hollow bells because of the difficulty of carving it, the natural resonance of certain kinds has attracted the interest of peoples in scattered parts of the globe, and it deserves a word here.

Besides the use of tuned stones in Confucian temples and elsewhere in the Orient, single resonant stones, or rock gongs, are still employed as a substitute for bells in the Coptic Church of Ethiopia and have been seen as far away as Venezuela. During the last century, sets of stone chimes were even given public performance in Europe.

It has but recently been discovered that bar-type stone chimes—horizontal slabs—have had a role in the ancient

culture of Vietnam. In its temples have also resounded the largest vertically suspended stones (up to several feet long and four inches thick) to be found anywhere.

Baked or hardened clay has long been a bell material. Though most bells so made have been chiefly for ornamental purposes, porcelain bells were created by Dutch craftsmen as early as the seventeenth century and rung in a musical way. Even the ancient Greeks played on tuned series of pottery bowls, and sets of porcelain cups have continued into more recent times in India and other parts of Southern and Western Asia.

It remained for the famed Meissen Porcelain Factory (founded in 1710 and the oldest maker in Europe) to successfully cast and tune sets of porcelain bells in modern times. Paul Börner, engineer and probably the foremost artisan of this century in the working of porcelain—especially large figurines—is responsible for the fabrication of four sets of tuned porcelain bells still in existence. His first masterpiece, made in 1929, resides in the belfry of the Frauenkirche in Meissen; the other sets are at Lüneburg, in Dresden, and more recently (1960) in the yard of the porcelain factory itself.

Professor Börner informs this writer that a special type of finely ground clay is used, which is placed on a mold and shaped by turning, as on a potter's wheel. The great difficulty of working with this material, whose shape must be kept precise, limits its size to a height of about 20 inches. After baking, the bell is brought into exact tune by grinding the rim, in much the same manner as is done with bronze handbells. The drawing on page 80 shows the relative sizes that comprise a set with a range of a little more than three octaves. Five basic profiles are used, each of which is shortened in graduated amounts to produce the chromatic scale.

While at least one of these sets is operable from a keyboard, the usual manner of ringing is by automatic play, whereby wooden hammers covered with felt are

made to strike the outside of the bells a little above the rim. So does this quaintly intimate music embellish the daily lives of those fortunate enough to live within hearing.

St. Rombaut's Cathedral in Mechelen, Belgium, houses a 49-bell carillon that is the world's most famous carillon. The cathedral, just off the town square, has been the traditional seat of carillon art since the sixteenth century.

The Nieuwe Kerk at Delft, th Netherlands, with typical Dutch su pension of carillon bells in u louvered openings.

7 Carillon Art in the Low Countries

THE TOLLING BELL may proclaim, give warning, summon, cheer, or spread tranquility. Its tone may in turn be merry, delicate, solemn, or mournful. Furthermore, it evokes patriotic, romantic, and religious sentiments and serves to unite a community by lending it a public voice.

Schiller, Longfellow, Poe, Tennyson, Thoreau, Hugo, and Galsworthy have all paid homage to its glory. Legend has endowed it with magical qualities, and superstition associates any disaster to it—as cracking or unauthorized tampering—with human disaster.

So is it small wonder that the bell's evocative sound has been considered a tonal medium worthy of artistic expression!

With a populace already conditioned to the melodious

This 1895 photograph shows the largest bell ever cast in the United States being transported to St. Francis de Sales church in Cincinnati, Ohio. The bell is an exact replica of England's Big Ben, and was cast by Van Duzen of Cincinnati.

strains of the clock chime as a regular accompaniment to daily activity, the keyboard play of bells quickly gained popularity throughout the Lowlands and gave rise to a new tradition—their musical offering coinciding with scheduled events in the street below. Nationalistic folk songs and other appropriate fare could thus enliven open market days, religious festivals, memorial days, and other occasions of celebration. The carillon, a folk instrument, was destined to play a unique role in the cultural life of the community.

Compared to present standards, the early instruments were primitive. Bells of uneven quality and limited range were given voice by rather crude playing actions. The professional skill of founders, from all indications, was far from uniform.

As time went on, however, those engaged in this enterprise began to attain an enviable status, and a few were to earn wide reputations as master craftsmen. When the introduction of gunpowder in the fourteenth century led to the new profession of weapon making, bell founders, with their bronze casting facilities, were admirably equipped to move into this lucrative sphere—bells and cannons were cast of the same metal. Over the centuries, wars have had this ironic effect: the founder's business prospers through the need for cannon, and when the fighting is over, his business continues as he replaces bells the cannons destroyed and bells that were melted down to make weapons. Hopefully, the bells will celebrate the victory the cannons have made possible! Even the manufacture of statues of heroes created by wars has been an important phase of founders' operations.

For a while most secular founders did not maintain fixed establishments but moved about the land—even from country to country—casting bells on or near the spot where they were to be hung; consequently, they were known as *itinerant* founders. This custom is understandable because means of transporting sizable bells were lacking, or at best inadequate. It was simply more expedient to bring equip-

ment to a site, dig a hole for a casting pit, and upon completion of the task, hang one's bells in the nearby tower.

Moving about as they did, these itinerant founders had an opportunity to inspect the bells of their colleagues and ascertain their various merits. This familiarity with one another's products, and sharing of knowledge, worked for the mutual interest at a time when further research was needed in the quest for the perfect bell.

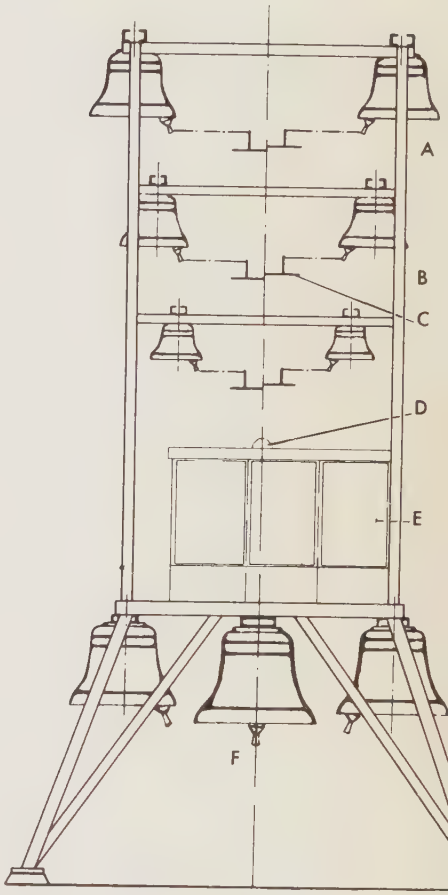
Because bells in most of Europe represented the output of numerous itinerant founders, all reflecting the respective points of view and methods of their makers, *regional* bell types (profiles) of national identification did not develop until founders settled down in one location and began working more independently. The establishment of permanent foundries permitted more leisurely operations and better opportunity to experiment with different casting techniques and profiles as well as to work with better equipment than could be carried about. As a result, a bell of improved musical quality gradually evolved.

The practice of casting on site nevertheless did not entirely cease but continued even into the nineteenth century. Casting ovens were sometimes set up inside a church itself, and records exist of bills submitted for repairs to the premises following such operations.

Generally the bells of the early *voorslags* and carillons were but superficially tuned, even though profiles had reasonably accurate proportions. Various reasons can be advanced: (1) Adequate grinding tools had yet to be developed. For many years the final correction of profile was done by crudely chipping away metal in the area of the rim. (2) Accurate means of measuring frequencies—especially of treble bells—were lacking. (3) Not all founders were sufficiently concerned with their bells' inner tuning, that is, their partial structure.

Undoubtedly, the initiation of human play stimulated more serious attention being given to precise tuning. From this time on, founders were also under pressure to expand

Carillon bells are hung in variou arrangements depending on space number and size of bells, an height of tower. When the bass bell are large, they are usually place below the playing cabin in orde to make a better tonal distribution



Key to the arrangement above

A: Middle octave.
B: High octave.
C: Carillon transmission system.
D: Umbrella assembly to preve water seeping onto clavie (One founder uses a wate absorbent material at this loc tion.)
E: Playing cabin.
F: Bass bells.

bell ranges to allow players more musical scope; by the seventeenth century it was possible to make and tune sets up to three and one-half octaves.

A few early carillon bells still exist. Among them are the three oldest in the famous instrument at St. Rombaut's Cathedral in Mechlin, cast in 1480, 1498, and 1515 by various members of the Waghevens family of that city. But for the most part, bells of this period gave way to improved ones as advances were made, until the advent of the Hemonys, whose superb carillons are still in use today.

The intense interest shown in bells by the Lowlanders surpassed that of most peoples and was responsible for the superior capabilities of their founders. The preoccupation with musical bells, and disposition to sound them together in harmony, gave far greater incentive to bell makers to seek perfection in tuning and timbre than existed in the creation of those bells used merely for marking the time or pealing. Thus, the craft of bell making attained its highest status in this small section of Europe, and in the course of time the services of its founders were sought far and wide.

The Hemony brothers, Francois and Pieter, were born in the town of Levecourt in Lorraine. Both traveled independently around Western Europe casting bells until eventually they arrived at Zutphen in the Netherlands. There they made a number of carillons that attracted immediate interest, and their bells were soon recognized as vastly superior in quality to all previous ones. Their success was well deserved, and their fame spread. Not only were they expert craftsmen, taking great pride in their work, but they were blessed with keen ears for music. Painstaking research had resulted in their becoming accomplished metallurgists, and they were knowledgeable as well in the system of tuning, called mean-tone temperament, prevalent at the time.

Following their scholarly inclination, they sought the assistance of musicians capable of advising them on matters of timbre and tuning, with special emphasis on the *inner* tuning of bells. The Hemonys' most influential con-

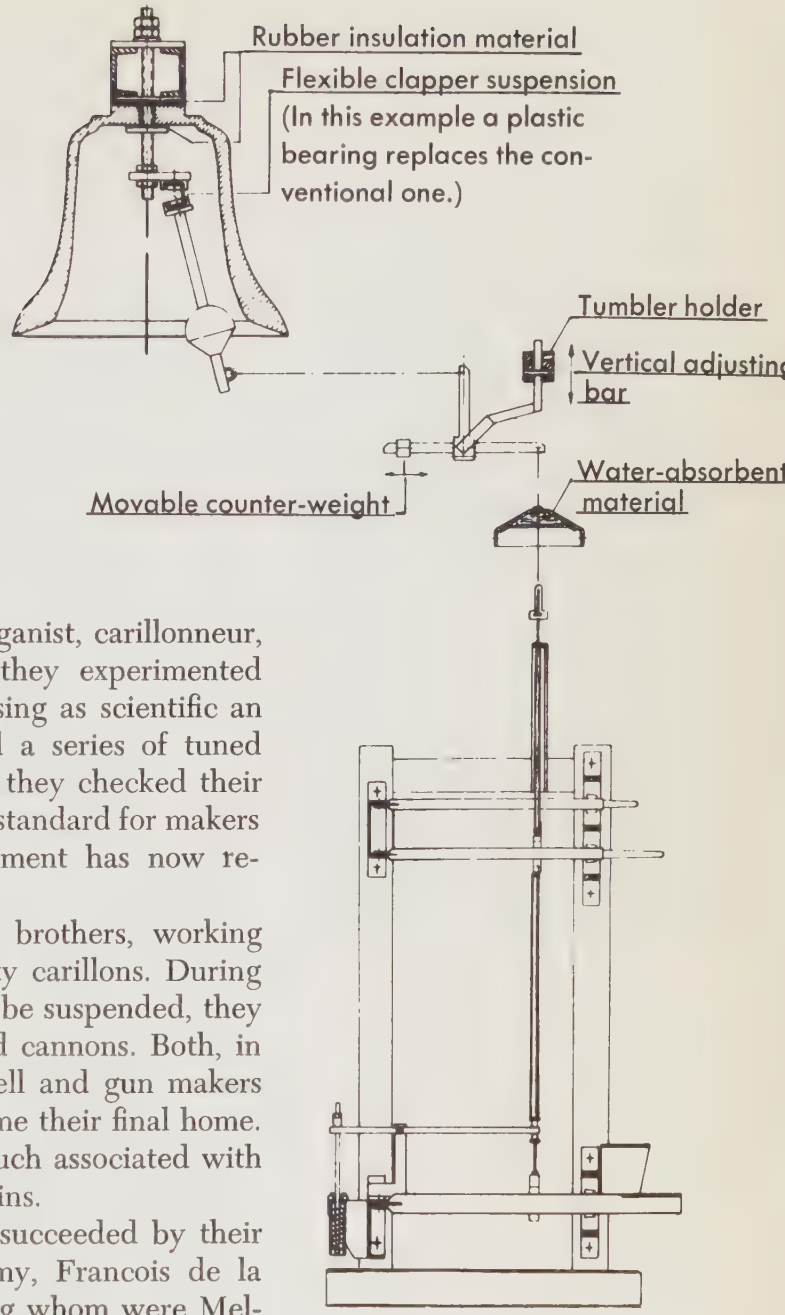


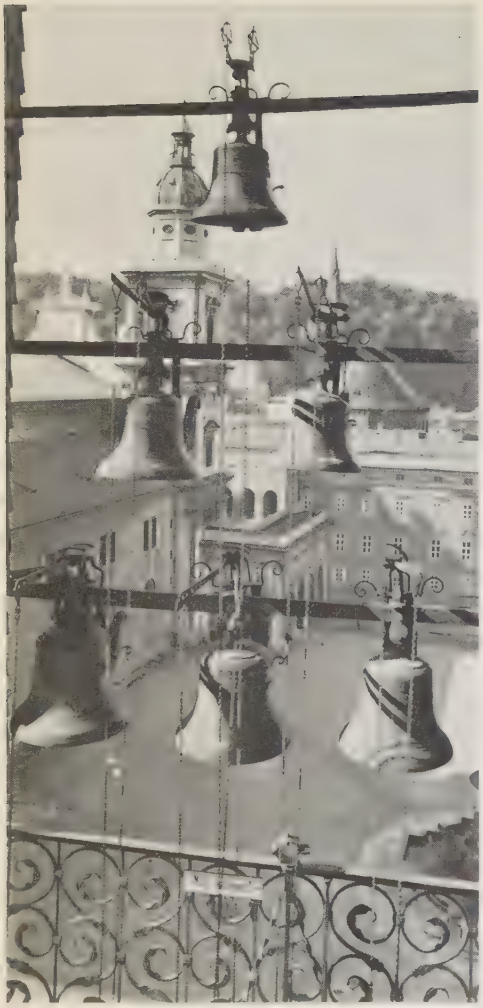
Diagram of carillon action most common today, known as the Tuimelaar System. The downward movement of the key is transferred into a lateral one by "tumblers" at right angles to each other.

sultant was Jacob van Eyck, a blind organist, carillonneur, and composer of Utrecht. Together they experimented with profiles and systems of tuning, using as scientific an approach as possible. They developed a series of tuned bars, called *stavenspels*, against which they checked their bells. Their results still serve today as a standard for makers of fine bells, although equal temperament has now replaced the mean tone.

From 1646 to 1680 these talented brothers, working either alone or together, cast some fifty carillons. During times of war, when bell making had to be suspended, they turned to the manufacture of guns and cannons. Both, in fact, had been appointed municipal bell and gun makers for the city of Amsterdam, which became their final home.

Today the name of Hemony is as much associated with fine bells as is Stradivarius with fine violins.

On their death, the Hemonys were succeeded by their pupils, Claude and Mammes de Fremy, Francois de la Paix, Claes Noorden, and others, among whom were Melchoir de Haze and Andreas-Josef van den Gheyn. Unfortunately, none of the pupils could measure up to the masters, try as they would to maintain the high standards of their predecessors. It is possible that the Hemonys were



View from belfry of Neubau Tower in Salzburg, Austria. The bells are six of thirty-five in a Glockenspiel imported from Antwerp in the late seventeenth century.

less adept as teachers than they were as craftsmen—or perhaps they were simply reluctant to pass on all of their trade secrets. Whatever the case, the art of bell founding went into a decline which continued over the next two centuries. It is further testimony to the genius of the Hemonys that even with their bells available for anyone to analyze and imitate, no one was capable of achieving comparable quality. Not until toward the close of the nineteenth century did bell making begin an ascent that led to a restoration of its former glory.

Since 1930, bell founding in Belgium and the Netherlands has made great strides, though still trailing its revival in England by a generation. During World War II innumerable bells were removed from towers and many others in Europe were destroyed, but in the postwar years there has been a tremendous resurgence of interest in the carillon in both Belgium and Holland. In addition to the many new instruments that have been installed, the historic Hemony carillons have been restored and in many cases enlarged to the four-octave range considered desirable today.

From the beginning of the sixteenth century to the end of the French Revolution, carillons spread persistently throughout the Provinces—a movement that reached its climax in the latter part of the seventeenth century with the superior Hemony instruments. Carillons were to become symbols of civic pride, with cities and towns vying in efforts to possess the most imposing instruments and largest bells of best quality. Often cities were not satisfied unless they boasted several carillons, and even the smallest hamlet found a place for one. While the church or town hall tower was the most common site, carillons were sometimes located in an abbey or even a palace. A few bell towers were freestanding—called campaniles. From its lofty position, in most instances in the center of the city, the carillon's melodies wafted down to beguile the passersby.

The impressive towers housing these "public voices,"

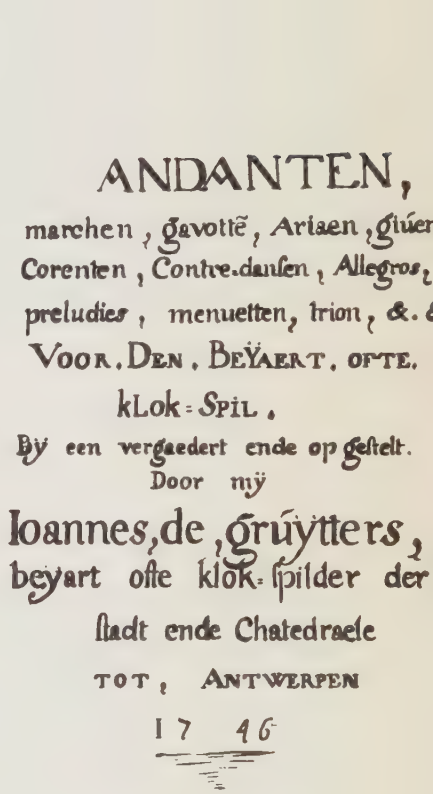
usually masterpieces of architectural beauty, were proud symbols of municipal power and independence. Church towers often played a dual role, representing the aspirations of both Christianity and the civic organization.

More often than not, the jurisdiction over the carillon, and its player, lay with the town council, in spite of the fact that the carillon might be located in the church tower. Sometimes this arrangement led to dispute, as it did at Antwerp Cathedral, where the civic administration and clergy resolved their differences by installing a second carillon in the same tower—one above the other! Only one of these carillons is operative today, although several bells from the other remain.

The city of Mechlin must be credited with the distinction of creating the world's first post of municipal carillonneur in 1557, at St. Rombaut's Cathedral. By this time the cathedral's instrument was so famous that delegations were sent from other cities to examine it before ordering their own. Perhaps by chance, greater interest in carillon art was developed at Mechlin than anywhere else. In any event, Mechlin became the carillon's focal point during the succeeding centuries and has maintained that status ever since. Its prestige was only once endangered, when installation of Hemony bells elsewhere brought the realization that Mechlin's were inferior. This intolerable situation was remedied in 1679, when a set of thirty-three bells cast by Pieter Hemony some years earlier were purchased and installed ceremoniously in 1680. These bells (only twenty-seven remain today), added to the eleven retained from the former set for a total of forty-four, made Mechlin's carillon one of the largest and best at that time.

It is housed in St. Rombaut's magnificent Gothic tower, 319 feet high, which is not only the most impressive in the Lowlands but also one of the most imposing in all Christendom. Had it ever been completed, it would have reached a height of 488 feet.

A century after the death of the Hemonys, and the subsequent decline of bell founding, the carillon was dealt


ANDANTEN,
marchen, gavottē, Ariaen, gluer
Corenten, Contre.dansen, Allegros,
preludies, menuetten, trion, &.
VOOR. DEN. BEYAERT. OFTE.
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TOT, ANTWERPEN
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The title page of the Carillon Book of Joannes de Gruytters, who was organist and carillonneur at Antwerp Cathedral.

Practice clavier of the Yale University carillon. Tuned metal bars, with resonators for amplification, supply the sound.

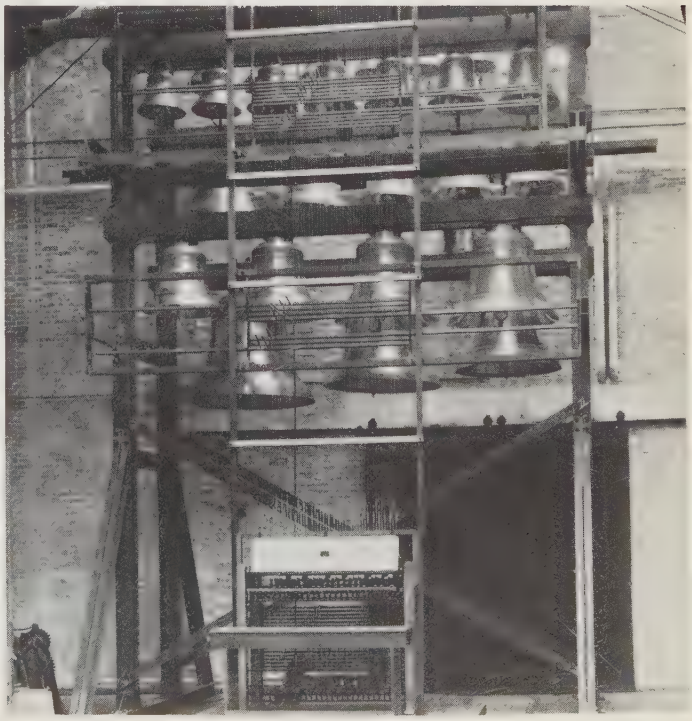
an even more severe blow. As an aftermath of the French Revolution and Napoleon's later ventures, a great many bells were removed to be cast into cannons, and no less than two-thirds of all carillons were destroyed. In the succeeding turbulent years, carillons that remained fell into disrepair. New bells were generally inferior, and the quality of playing deteriorated. Naturally, public interest waned. Bells, as an instrument for musical play, hit an all-time low during the nineteenth century. Although bell casting continued, correct tuning became a lost art. Technical knowledge was forgotten, and too often the father-to-son transition broke down as orders for new carillons slackened or ceased. Nevertheless, during these dismal times the carillon at Mechlin maintained its prestige and continued to be played without interruption.

A catalyst was needed to bring this national tradition into prominence once more, and toward the close of the century the right man appeared. In 1887 Jef Denyn (1862–1941) succeeded his father as municipal carillonneur of Mechlin. Immediately he was determined to

restore the carillon to its former place in his country's musical heritage. Possessing a magnetic personality, outstanding musicianship, and mechanical ability, his zeal inspired colleagues everywhere to emulate his example.

Denyn clearly saw the task before him. He realized that it was first necessary to improve the instrument itself, and this could be accomplished only by replacing the more objectionable bells and making the action quicker and more sensitive. This required mechanical changes, which he was able to make. But that was not all. He felt that he had to demonstrate the carillon's artistic merits by giving an enlightened standard of performance, and this soon proved to be the finest in all carillon history. It was now possible to repeat a note in rapid succession, leading to the introduction of a musical style based on the use of *tremolando,* which he exploited with great success.

With his genius increasingly recognized, Denyn's recitals eventually attracted audiences of tens of thousands, many of whom came in special trains from foreign countries to witness a type of musical performance heretofore unknown. Denyn had effected a true renaissance of carillon art.



Complete carillon set up in the foundry for testing. The clavier contains levers and pedals which are wired to the clappers.

Carillon in cupola of Royal Palace in Amsterdam consists of thirty-seven bells cast in 1664 by François and Pieter Hemony.

Two events of major significance occurred in 1922. First, a carillon school (now known as Royal Carillon School, "Jef Denyn") was established by Denyn in Mechlin, the first such school in history. Also, at this time, the carillon was introduced to North America, the first being installed at the Metropolitan Church in Toronto, Canada. The second was in Gloucester, Massachusetts, at the Church of Our Lady of Good Voyage. Following the Civil War, a few sizable sets of bells had been imported into America, to be sure, but their tuning was inferior and they were not playable from the conventional clavier; hence they cannot be regarded as true carillons.

By now Denyn's fame was worldwide, and many students from foreign lands were attracted to his school, which became recognized as the world center of carillon art. A publishing venture launched by the school—again a first—encouraged new compositions for the carillon and made available to carillonneurs the beginning of a badly needed literature.

The momentum generated by Denyn led to major improvement in carillon art, affecting the entire carillon world. Colleagues were greatly impressed by the brilliance and sensitivity of his playing as well as its tremendous emotional appeal. The expression of such artistry required the renovation of old carillons and insistence on major

improvements in new ones. Founders and carillonneurs alike were eager to cooperate.

During the 1890's, Denyn was aided in his pioneering by Canon A. B. Simpson, an English clergyman who had taken a lively interest in church bells, having become dissatisfied with their state in England. Simpson was instrumental in having their tuning given a thorough reappraisal. He took his ideas to the Taylor Bell Foundry in Loughborough, and the enthusiasm and energy he showed in his quest for improvement inspired journeys to the Lowlands for the purpose of analyzing the Hemony bells and learning their secret. Denyn supported and encouraged Simpson in his work, and they became close friends.

Although there had been a basic knowledge of bell acoustics in England, for many years bell profiles had been carelessly formed, with little attention given the matter of overtones. But as English bell ringing was strictly unharmonized, this was less relevant than on the Continent.

Simpson's involvement, as well as research by various physicists who had taken a similar interest—especially the

Seventeenth-century Hemony bell in the carillon in Nieuwe Kerk, Delft, the Netherlands. Its shape has been a model for all finely tuned bells.

renowned English scientist Lord Rayleigh—led to the restoration of a correct bell profile and rediscovery of the grinding process that produced the partial series found in the Hemony bells. Thus, by a curious turn of events, a founder foreign to the Netherlands gave the modern world its first well-tuned bells. And it was a foreign country, not the Netherlands, that was to take the lead in bell founding for almost half a century.

When Denyn died in 1941, his responsibilities were taken over by his brilliant pupil and assistant, Staf Nees (1902–1965). At war's end, he assumed a position of leadership in the carillon world. With great distinction, Nees fulfilled the role of performer, teacher, and composer. He was highly regarded by colleagues and public alike as a worthy successor to Denyn.

Then, in 1953, a second carillon school was established at Amersfoort, Holland, under the direction of Leen 't Hart, a Dutch carillonneur of outstanding ability. Several students have already completed their studies with him and have gone on to positions in Holland and elsewhere.

Few artists in any country have been as revered as Denyn was in Belgium. The reason was not simply an ability to stir the hearts of his countrymen with the magic of his music; Jef Denyn came to symbolize the flowering of a tradition beloved by the people and expressing—perhaps more eloquently than any other—what might be called the national soul.

The carillon (*beiaard* in Flemish, *klokkenspel* in Dutch) can be described as consisting of at least twenty-three cup-shaped, cast bronze bells, tuning in chromatic series and capable of sounding together in a harmonious relationship. Traditionally, it is played by means of a clavier containing levers and pedals which permit an expressive control over the bells. Occasionally there is an ivory keyboard operating the clappers by electric action. No dynamic control, however, is possible with this method of play, and it is usually employed only when a skilled clavier player is unavailable. But this keyboard, whose connection

with the clappers is solely through an electric cable, can be placed in locations removed from the belfry—as beside the organ console; the mechanical clavier, on the other hand, must remain near the bells.

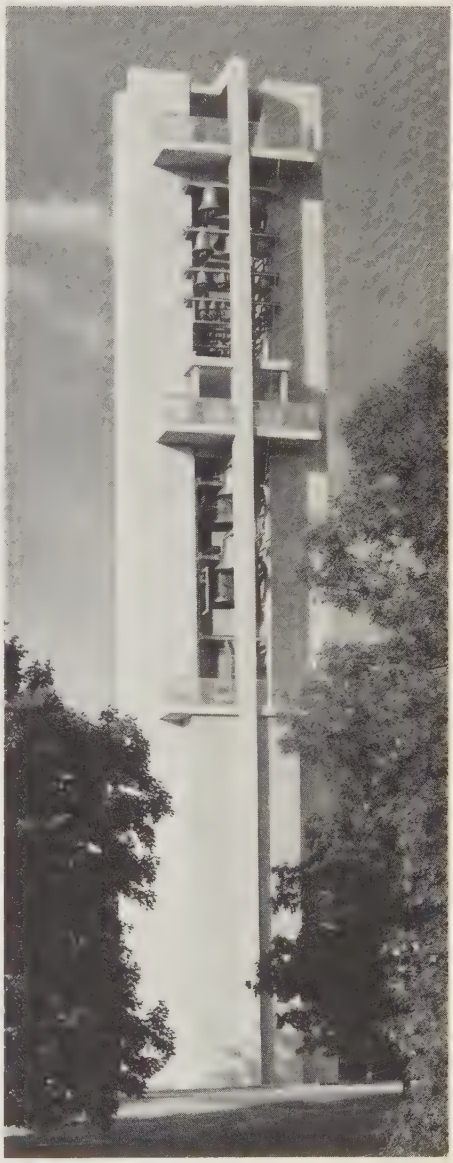
An indispensable accessory is the practice clavier, a replica of the regular one, whose sound is produced by tuned metal bars. While this device is not entirely satisfactory, it nevertheless is useful for acquiring the basic technical skill—in the privacy of the studio.

Although a carillon can have in excess of seventy bells, most today have between thirty-five and forty-nine. A frequent range is four octaves, starting on about middle C and encompassing forty-seven bells. These bells are stationary; only their clappers swing. They are usually suspended in a steel framework, although wood is still sometimes used and there are some who claim that it gives a purer tone. The carillon, then, lacks the uniformity of the conventional instrument, a feature shared with the custom-made pipe organ. Each bell instrument has its distinctive personality: it may be grandiose or intimate—and is usually immensely charming!

The carillon is played by using the fists to depress the clavier's wooden keys—sometimes called batons. Similarly, the feet control the pedals. The depression of key or pedal swings the clapper by means of a wire connection, and the amount of force applied controls loudness.

Traditionally there has been an air of informality about the carillonneur's presentation; in fact, very often his performance is partially improvised, which imbues it with a spontaneity that establishes instant rapport with the public below. Removed as he is, in his isolated position atop a tower, from any personal contact with his audience, the player must hold its attention by projecting an artistry endowed with imaginative and even dramatic qualities.

It may seem surprising that formal recitals were not introduced until 1892, when Jef Denyn initiated an evening series on a weekly basis at St. Rombaut's, with a view of arousing greater public interest. Since then, such recit-



Rees Memorial Tower, Springfield, Illinois, is a striking example of a carillon in a modern setting. There is now a trend to expose carillon, church, and chime bells to view.

als have become commonplace on carillons throughout the world, although routine periods of play are also common.

Formal recitals have tended to stimulate original composition (as apart from arrangements), and in this century alone more has materialized than was created in all previous centuries.

The preponderance of carillon repertoire, however, consists of music originally written for other media. Arrange-

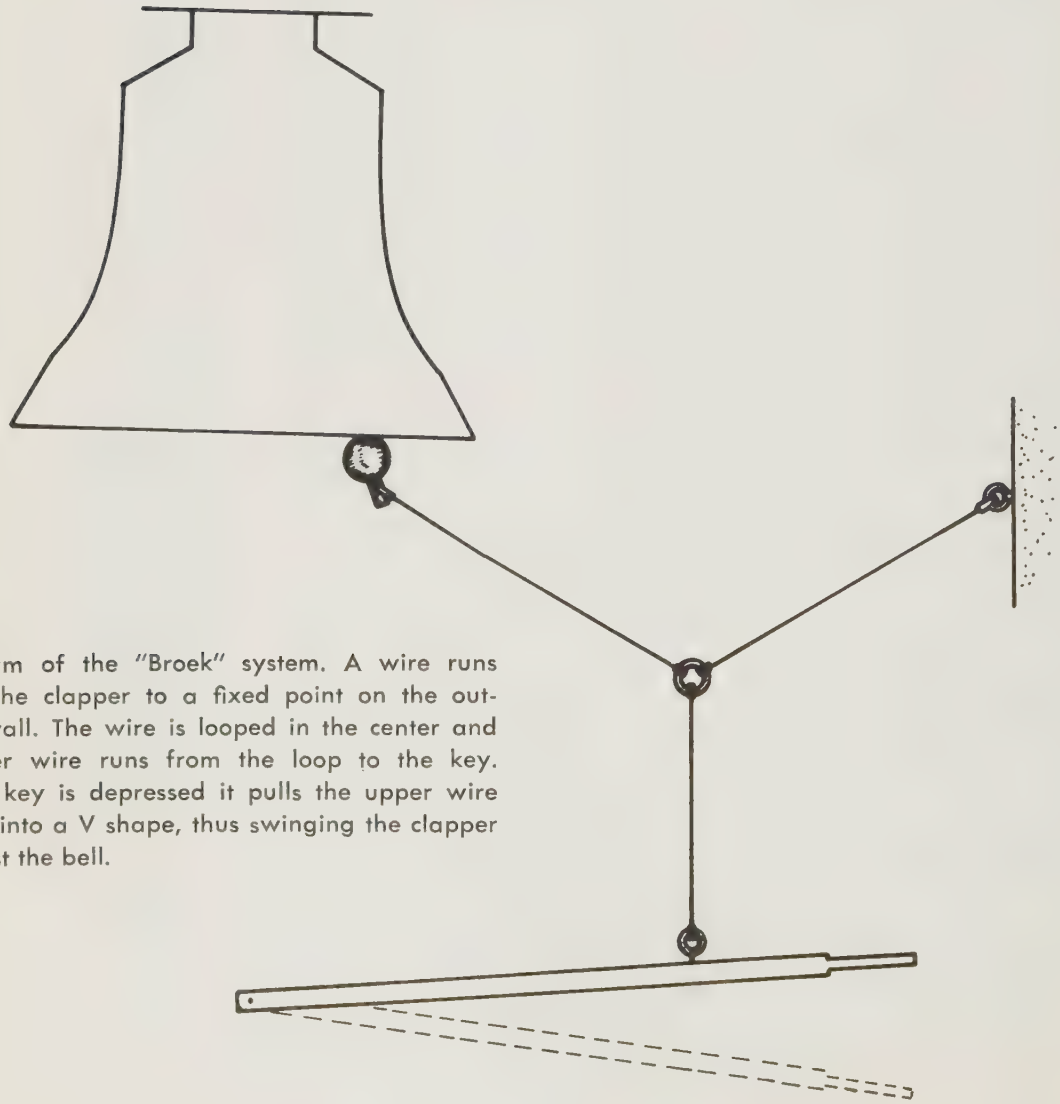


Diagram of the "Broek" system. A wire runs from the clapper to a fixed point on the outside wall. The wire is looped in the center and another wire runs from the loop to the key. When key is depressed it pulls the upper wire down into a V shape, thus swinging the clapper against the bell.

ments made from classical, sacred, and operatic sources, both vocal and instrumental, together with a wealth of folk melodies, have dominated programming. This is supplemented by a lesser amount of original composition which helps display the carillon's musical versatility.

The carillonneur, unlike other performers, must himself create the bulk of his library.

Most of the music of past players has disappeared. For various reasons, none was ever published, and private collections were lost or destroyed over the years. But early in this century a significant collection came to light. This is the *Carillon Book* of Johannes DeGruytters (1709–1772), organist and carillonneur at Antwerp Cathedral. It consists of 194 compositions and arrangements that provide some of the earliest examples of carillon music. Among these are original preludes, marches, dances, airs, allegros, and other short pieces, as well as a number of arrangements from contemporary instrumental sources. Generally speaking, this music is not unlike other clavier music; in fact, in many instances it is not clear if certain pieces were originally intended for carillon or were written for organ or harpsichord.

The second major source—still preserved but less in quantity—is a set of eleven *Praeludiums* and a few other short pieces by Matthias van den Gheyn (1721–1785), organist and carillonneur in Louvain, Belgium, who was considered the outstanding Flemish composer of his day. Although they do not show unusual originality, these *Praeludiums* represent the best effort of the time and remain favorites of today's carillonneurs. One of the most popular is the "Coucou."

Except for van den Gheyn, no prominent composer of the past has contributed to carillon literature. The chief reason was that carillon art was almost totally confined to the Lowlands and northern France and was unknown to composers living elsewhere. Had they been familiar with the instrument, it is quite likely the situation would have been otherwise, for a number—Handel, Michael Haydn,

W. A. Mozart, and Leopold Mozart—wrote a few pieces for automatic bell play. Certainly they would have been more intrigued by the artistic advantages of the human play. On the other hand, with the carillon now known throughout the world, a significant number of distinguished contemporary composers have begun to take an interest.

Such a meager inheritance is a handicap to carillon art today, since all art relies on the past in its evolution. Carillon music at its best is a distinctive idiom and not imitative of other instrumental styles. The challenge at present is to create a musical literature worthy of today's superior instruments.

Probably no term is more descriptive of the inherent nature of bell music than the "singing tower," a term often used in referring to the structure housing the carillon. Above all, the bells' singing quality and expressiveness are their most appealing characteristics. But the flowing cascade of liquescent sound descending from the singing tower belies the somewhat frenzied activity that produces it.

This is amusingly illustrated in the account given by the well-known English historian Dr. Charles Burney of a visit in 1773 to the belfry of Amsterdam's city hall to watch the performance of Mr. J. Potholt:

> At noon I attended Mr. Potholt, who is not young, and totally blind, to the tower of the Stad-huys or town-house, of which he is carillonneur; it is a drudgery unworthy of such a genius; he has had this employment, however, many years, having been elected to it at thirteen. He had very much astonished me on the organ, after all that I had heard in the rest of Europe; but in playing those bells, his amazing dexterity raised my wonder much higher; for he executed with his two hands, passages that would be very difficult to play with the ten fingers; shakes, beats, swift divisions, triplets, and even arpeggios he has contrived to vanquish.

He began with a psalm tune, with which their High Mightinesses are chiefly delighted, and which they require at his hands whenever he performs, which is on Tuesdays and Fridays. He next played variations upon a psalm tune, with great fancy and even taste. When he had performed this task he was so obliging as to play a quarter of an hour extempore in such a manner as he thought would be more agreeable to me than psalmody; and in this he succeeded so well, that I sometimes forgot both the difficulty and defects of the instrument. He never played in less than three parts, marking the bass and the measure constantly with the pedals. I never heard a greater variety of passages in so short a time; he produced effects by the pianos and fortes, and the crescendo and the shake, both as to loudness and velocity, which I did not think possible upon an instrument that seemed to require little other merit than force in the performer.

But surely this was a barbarous invention, and there is a barbarity in the continuance of it. If Mr. Potholt had been put into Dr. Dominicetti's hottest human caldron for an hour, he could not have perspired more violently than he did after a quarter of an hour of this furious exercise; he stripped to his shirt, put on his nightcap, and trussed up his sleeves for this excution; and he said he was forced to go to bed the instant it is over, in order to prevent his catching cold, as well as to recover himself; he being usually so much exhausted as to be utterly unable to speak. . . .

Most carillon actions today are not as strenuous as this early one undoubtedly was; however, there is no denying that playing the carillon can be an arduous undertaking. But to appreciate the music of the bells, the listener must be at a correct distance, preferably in an environment of tranquility. Paraphrasing the old adage, we might say that the carillonneur should be heard but not seen!

Hicksville Public Library
Hicksville, N. Y.

Table of Weights and Diameters of Carillon Bells of Two Founders

Pitch	Weight (in lbs.)	Diameter (in inches)	Weight (in lbs.)	Diameter (in inches)
Eb	24,000	104		
E	19,936	97	18,700	94 1/2
F	15,680	91	15,950	89 3/16
F#	13,750	86	13,420	84 1/4
G	11,200	81	10,275	79 3/4
G#	9,500	76	9,515	75
A	7,840	72	8,030	71 1/16
A#	6,720	68	6,765	66 3/4
B	5,400	64	5,665	63
C	4,600	60 1/2	4,730	59 1/2
C#	3,950	57	3,960	56 1/4
D	3,470	54	3,300	52 15/16
D#	2,900	51	2,750	50
E	2,400	48	2,332	47 1/4
F	2,050	45 1/2	1,910	44 1/2
F#	1,750	43	1,683	42 1/8
G	1,450	40 1/2	1,408	39 3/4
G#	1,290	38	1,188	37 3/8
A	1,120	36	1,000	35 7/16
A#	950	34	836	33 1/2
B	820	32	704	31 1/2
C	700	30 1/2	583	29 3/4
C#	620	29	484	28 1/8
D	530	27 1/2	407	26 9/16
D#	420	26	341	25
E	390	25	290	23 5/8
F	350	24	253	22 1/2
F#	310	23	220	21 1/2
G	280	22	198	20 9/16
G#	250	21	176	19 11/16
A	220	20	154	18 3/4
A#	190	19	141	17 15/16
B	155	18	130	17 5/16
C	130	17	119	16 3/4
C#	110	16	108	16 1/8
D	90	15	99	15 9/16
D#	80	14	90	15 1/16
E	65	13	81	14 1/2
F	55	12 1/2	75	14
F#	50	12	68	13 1/2
G	45	11 1/2	62	12 15/16
G#	38	11	57	12 1/2
A	34	10 1/2	53	12
A#	30	10	48	11 1/2
B	26	9 1/2	44	11 1/8
C	22	9	40	10 11/16
C#	22	8 3/4	37	10 5/16
D	20	8 1/2	35	10
D#	20	8 1/4	34	9 3/4
E	17	8	33	9 7/16
F	17	7 3/4	32	9 1/4
F#	17	7 1/2	31	9
G	17	7 1/2	30	8 7/8
G#	17	7 1/2	29	8 5/8

NOTE: Figures in this table are not rigid, but vary according to the particular instrument. They serve to show the individuality of founders. Differences in sizes should not be construed as indicative of relative merits, although tonal characteristics are affected.

Table of Weights and Diameters of Bells for Change Ringing

A table of comparative diameters and weights of bells used for change ringing and in carillons.

	Change ringing bells*		Carillon bells (two makers)			
Pitch of Bell	Diameter	Weight (in lbs.)	Diameter		Weight (in lbs.)	
			(a)	(b)	(a)	(b)
F#	28"	608	23"	21 1/2"	310	220
E	29"	627	25"	23 5/8"	390	290
D	31"	712	27 1/2"	26 9/16"	530	407
C#	32"	722	29"	28 1/8"	620	484
B	34"	851	32"	31 1/2"	820	704
A	37"	1,071	36"	35 7/16"	1,120	1,000
G	41"	1,450	40 1/2"	39 3/4"	1,450	1,408
F#	44"	1,733	43"	42 1/8"	1,750	1,683
E	49"	2,320	48"	47 1/4"	2,400	2,332
D	55"	3,588	54"	52 15/16"	3,470	3,300

The ten-bell "Ring" cast by Whitechapel Bell Foundry and installed in Washington Cathedral. The cathedral at Washington, D.C., rings to the intricate art of English change ringing.

Glossary

Archaic bell: Tower bell of the Middle Ages whose shape gradually evolved into that commonly seen today. Features include a straight tapered side, elongated waist, narrow top with rounded shoulder, and rather crude cannons for suspension.

Baton: Common name for the wooden key of the carillon clavier.

Beiaard: Flemish and Dutch for carillon.

Beiaardier: Flemish and Dutch for carillon player (carillonneur).

Bell: From Anglo-Saxon *bellan,* to roar. Old Norse *bjalla,* bell, from *bylja,* to resound. A hollow vessel, usually cup-shaped and of some hard, brittle material—in most cases metal—which is capable of ringing upon being struck near the rim. The striking agent in the Western world is normally of metal, but in the Orient is of wood.

Bell cage: Framework, formerly wooden but now usually metal, which rests on the bell deck rather than on beams embedded in the tower wall. Housed in it are bells mounted for swinging, as in English change ringing.

Bell deck: Term in England for the belfry floor.

Bell founder: One who makes bells, usually of bronze, by the casting technique (pouring molten metal into a mold).

Bell Founder's Window: At York Minster, England, on the north wall of the nave, is a finely detailed stained-glass window which was presented to the cathedral by Richard Tunnoc early in the fourteenth century as a unique memorial to the craft of bell founding. Included in its various scenes are representations of steps in bell casting, and there are no fewer than 200 bells featured in the design.

Bell metal: A bronze alloy of roughly 80 percent copper and 20 percent tin.

Bells of Justice: In China for many centuries a bell was hung outside the palace gate to be rung by a citizen seeking redress from some wrong or injustice.

Big Ben: England's most famous bell, located in the clock tower of the Houses of Parliament in London. It is named in honor of Sir Benjamin Hall, a man of large physique, who was chief commissioner of works in charge of its installation. Cast in 1858 at the Whitechapel Foundry in London, the bell has a diameter of 9 feet and weight of slightly more than 15 tons. Its distinctive sound is partly due to a crack in the rim which occurred shortly after the bell was hung.

Bourdon bell: Largest bass bell, whether in a chime, carillon, or peal—or simply a single large church bell. Exception: In the English "ring" of bells for change ringing, the largest is called the "tenor."

Bow Bells (of London): Ring of 12 bells at St. Mary-le-Bow, Cheapside, London, first cast in 1738 but recast several times due to periodic destruction. These bells are England's most famous set.

Broek (breeches) transmission system: Early action of carillon, still used in some carillons, especially in Holland and Germany. (Page 96)

Campana: Large tower bell.

Campaniform: Cup-shaped. Shaped like a bell.

Campanile: Free-standing bell tower.

Campanology: The study of bells and bell ringing.

Canon A. B. Simpson: English clergyman whose interest in improving the quality of church bells during the closing years of the nineteenth century led to the rediscovery of the tuning process perfected by the Hemony brothers, knowledge of which had become lost both in England and on the Continent.

Cantigas de Santa Maria: Book of musical poetry written by Alfonso the Wise in the thirteenth century, in which are described all contemporary musical instruments, including sets of bells (with illustrations).

Carillon: a. From medieval Latin *quadrilionem,* which refers to four stationary bells commonly used in France to indicate the time. Three high-pitched bells chimed the quarter-hours, while a fourth—and deeper-toned one—tolled the hour.

b. A set of cast bronze bells arranged in chromatic order and so tuned as to be capable of concordant harmony. They are normally played from a clavier of wooden keys and

pedals but may also be played from an ivory keyboard with electric action.

Carillion: Anglicization of *carillon;* a term chiefly employed in Great Britain.

Carillonneur: Term most widely applied to the player of the carillon. (*See also* Beiaardier; Klokkenspeler.)

Casting pit: Large bells of several tons are normally cast in a hole dug in the ground because of the ever-present danger of the mold's giving way and spilling out the molten metal.

Chaghāna: Called Turkish crescent, *chapeau chinois,* or jingling johnnie. A ceremonial staff of ancient Central Asian origin which was adopted by the Turks and gained importance following their capture of Constantinople, when the crescent became the emblem of Turkish power. This symbolic and highly ornate staff is surmounted by a crescent and a metal ornament shaped like a Chinese hat. Attached are two horsehair tassels, and hanging at different points are a considerable number of bells and crotals which jingle as the staff is carried in procession. The chaghāna was highly valued by Europeans as a war trophy during periods of conflict with Turkey and was incorporated in miltary bands following the Turkish custom. It still exists today.

Change ringing: A traditional English practice, having its beginnings in the fifteenth century, whereby a series of bells is rung in mathematical permutations. The sequence of the changes is based on a "method" which has been previously composed. Ringing is done by pulling ropes which swing the bells in full circle. (*See also* Ring; Peal.)

Chime: Early English term was *chymme bells,* from *chymbals,* an Anglicization of the Latin *cymbala.* A set of bells usually numbering up to 16 (but not more than 22) and hung stationary. They are played melodically—occasionally with simple harmony—either by automatic action, from an electric keyboard, or from a chime stand of wooden levers and sometimes pedals. If sounded automatically, the chime may be set off by clock action or by controls which permit designated periods of play. *To chime* refers to the automatic ringing of the bells of the chime. In England it also refers to the ordinary swinging of a church bell in a limited arc (as opposed to the full circle of 360 degrees for bells in change ringing).

Chiming cylinder: Also called chiming barrel or drum. Metal cylinder—sometimes wood—whose surface is perforated, often with thousands of holes, for receiving projecting pegs or cogs. Mounted on a horizontal axis, it is made to rotate, in the early days by a suspended weight whose cable unwound from the barrel shaft. The pegs engage levers attached by wire to hammers mounted outside the bells, and as the barrel revolves, the levers are pushed down, thereby pulling the hammers away from the bells. When the levers become disengaged, the hammers fall through a spring to strike the bells. Sometimes there are as many as five hammers per bell in order to permit the rapid repetition of a note.

Chinese bells and other idiophones (selected list):

Bell pavilion: A low structure of wood or masonry whose bell hangs a few feet off the ground. It is the housing in East Asia for the main temple bell.

Ch'ing ("resting bell"): A metal bowl placed open side up on a cushion and struck with a stick. It is used in Buddhist and Taoist services.

Chung: General name for all bells without clappers.

Chung lou: Bell tower. A municipal tower of moderate height whose bell signals the time of day, sounds the curfew, and warns of common danger.

Feng Ling: Wind bell hung under corners of roofs of temples, pagodas, pavilions, public buildings, and private houses.

Hsü Pan: Hanging resonant board used in monasteries for various signaling purposes. Producing a sort of ring, it might be regarded as a wooden substitute for the metal bell. Similar boards have been used in other parts of Asia and in Europe. (*See also* Semanterion.)

Ling: Small bell with clapper, hand-rung by Buddhist and Taoist priests.

Lo: Circular brass gong.

Mu Yü: Wooden fish of highly ornamented camphor wood, partly hollow with a loose wooden pellet inside. Struck with a knobbed

stick, it produces a short ring of recognizable pitch.

Pien Ch'ing: Chime of 16 L-shaped marble stones suspended in a framework in two rows of eight and used in the Confucian service in conjunction with the *Pien Chung*. They are struck with mallets. Dating from neolithic times, the *Pien Ch'ing* is one of the oldest of musical instruments.

Pien Chung: Chime consisting of 16 tuned bronze bells placed in two rows of eight in a rectangular framework and played by priests using mallets. Dates to at least 2000 B.C.

Po Chung (metal counterpart of T'e Ch'ing): Single bell suspended in a framework, which is used in Confucian services. There are two *Po Chung*, one for spring and another for fall.

Ta Chung (Great Bell): Term applied to huge bells in temples, monasteries, or municipal towers.

T'e Ch'ing: Single L-shaped slab of sonorous stone suspended in a framework and used in Confucian services. Each temple has two, as with the *Po Chung*.

T'ish Ma, Yen Ma,Yü K'o: Small plates of metal, stone, or glass, hung under eaves or in doorways to jingle in the breeze. Of ancient origin, these wind chimes are now familiar to everyone.

Yung or *Yung Chung:* Main bell (and largest) of the Confucian temple.

Clapper: A striking agent suspended inside a bell, consisting of a shaft with a solid metal sphere at the end.

Clavier: Console of wooden levers and pedals, the means of playing the bells of a carillon.

Clepsydra: Water clock used by Chinese and Romans. The latter sometimes attached a bell, thus making their clocks the first to chime.

Clocca: Medieval Latin for bell. (*See* Monastery bells.) *Klok* (Dutch), *Glocke* (German), *cloche* (French)—all meaning bell—derive from the Latin. Even our word *cloak* (bell-shaped) comes from the same root.

Clock jacks (Jacquermarts): English term for mechanical figures, often a pair of armored knights, which strike a bell with battle-axes to indicate the time.

Clocking: In England, the ringing of a few stationary bells to announce the time by pulling ropes to swing clappers.

Cote (Bell cote): A housing for a suspended bell in the form of an arched opening in a thick masonry wall. Bell cotes traditionally have been a Spanish architectural practice but nowadays are being incorporated in contemporary structures.

Crotal: One of the oldest types of bell. It is a small perforated sphere, usually of metal, inside which are loose jingling pellets.

Crown: Also known as canons or cannons. Two loops at right angles to each other are welded to the head of a bell. This has been the method of hanging bells since cast bells first appeared in the Catholic Church. A majority of church bells made today, however, lack crowns and are bolted directly to a beam or headstock. In the British Isles, crown refers to the top of the bell proper, and cannon to the loop for suspension.

Cymbalum (Pl., Cymbala): From Greek *kýmbalon*, hollow vessel. Medieval Latin for bell (and specifically one struck by hand with a hammer). In earlier times it meant cymbal. Since cymbals were slightly convex with a hemispherical center, they bore a resemblance to the cuplike bell. Some cymbals eliminated the rim entirely and thus were exact hemispheres. This similarity accounts for the borrowed name. (*See also* Chime.)

Czar Kolokol (Emperor Bell): Commonly called (incorrectly) the King of Bells. At 222 tons it is the largest bell ever cast. Completed in 1735, it was still in its casting pit when a fire in 1737 caused a large chunk to be broken off. It was raised in 1836 and placed on a pedestal beside the Tower of St. Ivan in the Kremlin, where it still stands.

DeGruytters, Johannes (1709–1772): Carillonneur and organist at Antwerp Cathedral; his *Carillon Book* of 194 pieces is the largest single source of carillon music from the past.

Denyn, Jef (1862–1941): Belgian carillonneur; the most distinguished in carillon history.

Doppler effect: Slight change in pitch noted when one moves rapidly toward or away from a sound source (or when the latter moves toward or away from the ear). Upon approach, the pitch sounds a little higher; when receding, a little lower.

Drohndorf, Germany: Location of the oldest known dated bell in Europe (A.D. 1098).

Drum gong (or kettle gong, bronze drum): Unique version of the deep basin gong indigenous to Indochina and environs. It was first used around the time of Christ by aboriginal tribes (the Miao) in regions bordering on the south of China for a war summons and to accompany prayers for rain. Its stylized, decorative flat head, in whose center is a 12-rayed sun from which radiate 21 concentric zones containing geometric designs, suggests the taut skin of a drum. Some gongs possess ornamental frog figures symbolizing fertility, others the egret (bird figure). They have survived down through the years and are even used today.

English handbells: Sets of tuned bells rung by hand, whose original purpose in the seventeenth century was to permit the private practicing of change ringing before moving into the tower. A by-product was the expansion of some sets for musical use, that is, the performance of melodies with harmony. The latter is now most common in the United States, where there are thousands of sets. English handbells should be distinguished from other types of handbells, in England and elsewhere, that are rung for other purposes.

Equal temperament: The present system of tuning bells (and other instruments), whereby all half-tones are identical; the octave is divided into 12 divisions of 100 "cents" each.

Erfurt Cathedral, Saxony: Bourdon bell at Erfurt Cathedral, weighing 14 tons, was cast in 1497 by Dutch founder Geert van Wou. In its early years it was the most distinguished (and largest) bell in Western Europe, being of superior tone and with partials in perfect alignment. It still rings today.

Glockenspiel: German for carillon or chime. (*See* Voorslag.)

Gong: A round metal plate of bronze or brass with turned drumlike edge, with or without a raised center (boss) and struck with a knobbed wooden mallet. The gong may be suspended either vertically or horizontally, and its side can range from a shallow lip to one of several inches, resembling an inverted cauldron. Its resonance is greatest at the center and least at the lip.

Great Bell of Kyoto: This impressive barrel-shaped bell at 74 tons is the world's second-largest ringing bell. Cast in 1633, it is 17.9 feet high, 8.9 feet in diameter, and about a foot thick. On its upper wall are three fields of knobs or bosses totaling 108 (a symbolic number). It takes sixteen priests to ring it, which is done by swinging a huge wooden ramrod suspended on chains. The bell hangs in a low belfry near the Chion-in Temple in Kyoto, Japan.

Great Bell of Peking (or China), called Ta Chung. One of the world's most celebrated bells, this masterpiece was cast around A.D. 1420 during the reign of the third Ming emperor, Yung-lo, as a memorial to the removal of the national capital from Nanking to Peking. It is China's largest, reputedly weighing around 60 tons, with a height of 14 feet and diameter of 10 feet. It is in the form of an elongated bowl with dome-shaped top and lotus rim. At the top is a large hole made for tonal purposes. Most striking is its decoration: extracts from Buddhist classics cast on the bell both inside and out, consisting of no fewer than 160,000 words. The bell still hangs in the bell temple of a Buddhist monastery on the western outskirts of Peking.

"Great Paul": Bourdon bell at St. Paul's Cathedral, London. Cast in 1881 by Taylor of Loughborough, its weight of 18¾ tons makes it the largest in the British Commonwealth.

Gudgeons: English term for pivots upon which rests the headstock of a swinging bell. The axis of the swing is at this point.

Hammer: With bells, an exterior striking agent of metal, pivoting from above, which is usually activated mechanically.

Head of bell: Top of bell proper and main node of its vibrations. In England, it is known as the crown. (*See* Crown.)

Hemony, François and Pieter: Seventeenth-century Dutch bell founders whose bells reached a perfection in timbre and tuning previously unequaled. Only in recent years have bells of comparable quality been made.

Horloge à carillon: French for chiming clock.

Hum tone: Lowest partial (frequency) of bell. In the carillon bell it is one octave lower than the prime tone.

Idiophone: Naturally sonorous body (as the

bell). One of the basic tone-producing media. Its vibrations are inherent in the material and are produced by striking.

Just Intonation: Mathematical computation of the scale which puts most notes in perfect alignment but results in two "wolf" or false intervals, off to the extent of a syntonic comma (22 "cents"). Some bells—when not sounded harmonically—have been tuned according to this system.

Klokkengieter: Dutch for bell founder.

Klokkenspel: Dutch for chimes or carillon. (*See* Voorslag.)

Klokkenspeler: Dutch for carillonneur.

Klokketoren: Dutch for bell tower.

Lancashire Ringers: Famous nineteenth-century group of English handbell ringers who performed worldwide. P. T. Barnum brought them to America in the 1840's, calling them Swiss Bell Ringers. The first full "peal" of 5,040 changes to be heard in the United States was rung by this group at Christ Church, Philadelphia, in 1850.

Leads: In a carillon, the wires from the keys terminating at the clappers.

Lester, Thomas: Proprietor at the Whitechapel Bell Foundry in London, where the original casting of the Liberty Bell was made in 1752.

Liberty Bell: America's most famous bell and emblem of liberty, located in Independence Hall, Philadelphia. It was first cast by Whitechapel of London in 1752 but had to be recast twice (by Pass and Stow of Philadelphia) before it could be used. It became immortal when it was used to call an assembly in the State House yard on July 8, 1776, for the reading of the proclamation declaring independence from England. Although its inscription reads PROCLAIM LIBERTY THROUGHOUT ALL THE LAND UNTO ALL THE INHABITANTS THEREOF (Leviticus 25:10), it did not assume its title of Liberty Bell until after 1839. The bell weighs 2,080 pounds, and is one of the earliest bells cast in the United States.

Lip (of bell): Same as rim. The bottom edge of a bell where inner and outer surface come to a point.

Liverpool, England: The bells in the Cathedral Church of Christ here constitute the world's heaviest ring, with a tenor bell of 4.6 tons. While twelve bells are maximum for a ring, a thirteenth is included to form a lighter scale whenever the heavier one is not desired.

Mean-tone temperament: The system of tuning employed for most bells from around 1500 to 1900. This temperament permits a closer conformity to the frequency ratios of the intervals found in the natural overtone series but limits the amount of transposition, the sharps not being identical with the flats.

Meridians: In a bell, those vertical nodal lines resulting from its geometric form which are associated with various wavelengths of the vibratory movement. (*See* Parallels.)

Metallophone: A type of musical instrument consisting of a series of tuned metal bars or slabs whose ringing sound is usually amplified by resonators. It first appeared in Southeast Asia around the tenth century. First its metal was bronze, but in today's celesta, glockenspiel, and vibraphone it is usually steel or an aluminum alloy. The Dutch borrowed the idea of the metal slab for the carillon practice clavier.

Mingun Bell: World's largest ringing bell (97½ tons). Located 7 miles north of Mandalay, Burma, it has a diameter of 16 feet, 3 inches, and height of 12 feet. It was cast in 1790 to accompany the nearby Mingun Pagoda, whose intended height of 500 feet would have made it the highest in the Orient. Due to the king's untimely death, however, the pagoda was never completed. The bell is still in regular use.

Mold (bell mold): Consists of an inner core of brick and clay, over which is placed an outer form called the cope. Molten metal—usually bronze—is poured in to fill the space between core and cope.

Monastery bells:

Angelus bell: Tower bell used as call to prayer in memory of the visit of the archangel announcing to Mary that she was to be the mother of Jesus. Its ringing consists of a triple stroke thrice repeated and followed by nine successive strokes (or else an indeterminate number). Dating from the thirteenth century, the angelus has traditionally been at 6:00 A.M., noon, and 6:00 P.M. Also customary in all Catholic churches.

Campana: Large tower bell for general use.

Campanella: Smaller suspended bell in the cloister.

Codon: Handbell for summoning.

Corrigiunculum: Rung as summons to flagellation or prescribed penance.

Cymbalum: Suspended bell in the cloister (smaller than campanella).

Dupla: Clock bell.

Noctula: Bell to call sleepers to prayer.

Nola: In the choir, rung at consecration of the elements.

Petasius: Suspended bell (sizable) for summoning.

Sanctus bell: Altar bell.

Signum bell: Tower bell—general-purpose bell for signaling. Among its functions is the ringing of the eight canonical hours: matins, lauds, prime, tierce, sext, nones, vespers, and compline.

Squilla: Dinner bell in refectory (and elsewhere).

Tiniolum: Evening bell rung to signal retirement.

Nabatny bell: In Russia, the public tocsin or alarm bell.

Nominal: Partial of tuned bell an octave above prime.

Parallels: Horizontal nodal lines positioned at different elevations on a bell's wall. These are associated with *vertical* waves of varying length and frequency. (*See* Meridians.)

Partial: Refers to one of the frequencies constituting a bell's ring. The five lowest partials in the tuned carillon bell are the most important.

Paulinus (353–431): Bishop of Nola in Campania, Italy. Tradition ascribes to him the distinction of introducing the first tower bell in the Christian church, but this is probably inaccurate.

Peal: A group of different-sized bells, usually from two to six, located in a belfry of the Christian church and rung according to the liturgical calendar and on other special occasions. Each bell of the peal swings at its own rate, thus producing an ensemble of disorganized sound. This ringing is referred to as pealing. In the British Isles, *peal* refers to 5,040 "changes" rung in continuous succession (*See* Change ringing) on a "ring" of bells. Seven bells or more permit this number of changes; if the ring contains fewer than seven, a peal will consist of the maximum number of changes possible on that number.

Practice clavier: Replica of the regular carillon clavier but with metal bars to produce the tone.

Prime tone: Synonymous with the fundamental tone of a tuned bell.

Primitive bell: Term now used to describe the earliest cast bronze bells in the Christian church, which superseded the earlier bell of iron plates hammered and riveted. With convex sides, it resembled an inverted bowl and has been referred to as the beehive bell. Its wall was of uniform thickness; in time a ring of metal was added to the rim as reinforcement—which later developed into the sound bow.

Profile (of bell): The geometric shape of a bell, including the wall cross section.

Pythagorean tuning: The prevailing tuning during the Middle Ages. All intervals of the fifth were pure (in accordance with the frequency ratio of 3:2), but as a result the thirds were false. This tuning remained in general use until superseded by the mean tone.

Quint: Perfect fifth partial (above prime) of a tuned bell.

Ring: A set of bells, numbering 3, 4, 5, 6, 8, 10, or 12, hung for change ringing (*See* Change ringing). Mounted to each headstock is a wheel from whose grooved rim a rope extends to the floor below. When the rope is pulled, the bell is made to swing in an arc of slightly more than 360 degrees. The bells are so arranged that the suspended ropes form a circle. The great majority of rings are in the British Isles.

"Ringing Isle": Term frequently bestowed on Great Britain because of its great number of tower bells and their frequent use.

Sacring bell: Small bell rung at the altar of the Catholic church during a sacred function. Also known as Sanctus or Holy Bell, tintinnabulum, and *parva campanula.*

Semanterion: Greek for signal. Hanging, or sacred, board, struck with a heavy wooden mallet. Probably first used in Europe by the Greeks in the Orthodox Church. Under differ-

ent names the hanging board has been found in China, Japan, the Balkan countries, the Ukraine, and elsewhere.

Shoko: Japanese flat gong suspended vertically in an ornamental wooden frame. It is employed in *gagaku,* or court music.

Shoulder (of bell): Curved area between the head and wall.

Singing Tower: Term sometimes used to refer to a tower housing a carillon.

Sistrum: Oval frame with handle in which are loosely placed metal crossbars which jingle upon being shaken. On the bars are sometimes strung small bells. While of ancient Middle Eastern origin, the sistrum came to be chiefly associated with the worship of the Egyptian goddess Isis.

Slider: Horizontal bar mounted on the bell cage directly beneath a bell so as to pivot slightly. It serves as a stopper when a stay contacts it upon a bell's reaching an inverted position. Only bells used in English change ringing have need for this device because of the full circle of stroke. (*See* Stay.)

Sound bow: Bulging area of the bell wall just above the lip.

Spanish mission bells in America (selected): *San José Bell,* dated 1356, hangs in the San Miguel Mission at Santa Fe. It is one of the oldest in the United States.

Jesus Nazareno Bell, cast in 1330, now on a private estate in the United States.

Cathedral of St. Augustine, in Florida, has a Spanish bell dated 1682.

Stay: In English change ringing, in which bells are required to swing in a full 360-degree circle, it is necessary to brake the movement of each bell when it arrives in "up" position in order to keep it from continuing in the same direction instead of starting its return. The stay is a projecting wooden arm or bar attached to the bell yoke which is stopped by a slider when the bell has reached an inverted position. (*See* Slider.)

St. Peter (Petrus) Bell, Cologne Cathedral, Germany: Weighing 27½ tons, it is the heaviest tuned and swinging bell in the world.

Strickle board: Also called sweep. A board whose inner side is contoured to the shape of the inner or outer surface of a bell. As it rotates on an axis, the contoured side forms the shape of the mold's core (inner surface of bell). When a "false" bell of clay is mounted on the core, a second and larger strickle board forms the outer contour of the bell.

Strike tone: Initial timbre and pitch of a bell upon impact, resulting from all possible frequencies at their initial amplitude. Its pitch corresponds with that of the fundamental, or prime tone.

Swiss Bell Ringers: A common designation in the nineteenth and early twentieth centuries for players of English handbells, especially in the United States. How this term originated is obscure; perhaps it derived from the Swiss custom of performing with cowbells.

Tapping (bells): Term applied in medieval England to playing cymbala (bells) by striking with two mallets.

Tenor bell: English term for the largest bell in a "ring" of bells used for change ringing. American founders in the nineteenth century borrowed the term to denote the largest bell in a chime, now called the bourdon.

Theophilus Presbyter: Eleventh-century Benedictine monk who wrote one of the earliest treatises on bells, outlining the problems involved in their casting and in the control of tone and tuning.

Tierce: Minor-third partial of the tuned bell.

Timbre: Tone quality resulting from a given alignment of fundamental and partials.

Tintinnabulum: Small bell. (*See* Sacring bell.)

Transmission bar: In a carillon, one of a series of horizontal bars set in bearings so as to rotate and located on a level with a corresponding clapper. Attached at appropriate points are two arms at right angles to each other; one has a wire lead to the clapper and the other to the key below. (*See* Tuimelaar.)

Trezvon: Most common form of bell ringing in Russia on the zvon; characterized by distinctive rhythmic patterns which have been formally composed for this purpose. On a zvon of sufficient bells, there will be three contrasting rhythms, emanating from the bass, middle, and treble registers. The trezvon represents the most impressive style of Orthodox ringing, especially on the heavier zvons, whose largest bells can weigh as much as 72 tons.

Tuimelaar (tumbler) transmission system: Modern action of carillon. Two arms at right angles are attached to a rotating bar, the vertical arm being connected by wire to a clapper and the horizontal arm to a key below. Depression of key results in a lateral movement of the vertical arm and wire, swinging the clapper against the bell.

Tulip-shaped bell: The shape of the typical tower bell since the fifteenth century, so called because of its general resemblance to the flower.

Turn-buckle: On the carillon, an adjusting device located just above the clavier for lengthening or shortening the wire connection between key and clapper.

Umbrella: In the carillon action, a means of preventing water from seeping from the belfry onto the clavier below through the opening where the wire leads of the action descend to the keyboard. A small brass sleeve (hollow cylinder) closed at the top is attached vertically to the wire and moves up and down over a stationary cylinder of smaller bore affixed to the belfry deck.

Uspensky Bell (Assumption Bell): In Kremlin, Moscow. Weighing 72 tons, it is the largest ringing bell in the USSR today, being part of the zvon of 34 bells in the Tower of St. Ivan and adjoining Chapel of St. Nicholas. It was cast in 1817 to memorialize the triumph over Napoleon in 1812.

Venerable Bede (673–735): Credited with earliest written reference to church bells in England.

Voorslag (forestroke): Flemish and Dutch for chime. Term applies both to the short automatically produced tune on the divisions of the hour and preceding the striking of the hour and to the set of bells themselves. English: *chime;* German: *Glockenspiel;* French: *carillon;* Dutch: *klokkenspel.*

Waist (of bell): Middle area of the bell wall.

Westminster Chime Tune: World's most common chime tune for striking the quarter-hours; originated at Cambridge University in 1793 and was known as the Cambridge Quarters until its later association at London's Westminster Palace (and with "Big Ben"), beginning in 1859, led to its present designation. The notes E, D, C, G are heard a quarter after the hour, followed successively by two phrases of eight notes, three of twelve, and four of sixteen—all on the same bells in different sequences reminiscent of change ringing.

Yoke: Synonymous with headstock. More common term in America for the inverted U-shaped frame, formerly wooden but now metal, in which a bell is suspended when it is to be swung.

Zvon: Russian term for a set of tower bells in the Orthodox Church which are rung liturgically and on various festive occasions by manually pulling ropes attached to inside clappers. Could loosely be translated as chime or peal.

Zvonari: Russian bell ringers who play the zvon.

The Author

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About the Record with Bells and Their Music

The record inside the back cover is a 33⅓ rpm recording of portions of the ringing of bells or groups of bells. Within this book you will find more details on each. Consult the index, glossary, and list of illustrations, under the names of the bell, the foundry, the structure (cathedral, etc.) where the bell is located, or the town.

Side One

1) Tolling of the "Maria Gloriosa" at Erfurt Cathedral in Saxony, Germany.

2) Rees Memorial Carillon at Springfield, Illinois. Dutch carillonneur Leen 't Hart plays "My Old Kentucky Home." (Courtesy, Leen 't Hart, carillonneur of Rotterdam, Delft, and Amersfoort.)

3) Carillon at the Nieuwe Kerk in Delft, The Netherlands. Leen 't Hart plays the Easter hymn "Christ the Lord Is Ris'n Today." (Courtesy, Leen 't Hart.)

4) Spartan Bell Ringers of Michigan State University plays the Swiss folk song "Hol-di-ri-dia" on English handbells from the Whitechapel Bell Foundry in London.

5) Glockenspiel at the Town Hall of Salzburg, Austria. Automatic play of Mozart's "Menuetto" from *Don Giovanni*. (Courtesy, Teldec Corp. [Telefunken Records], Hamburg, Germany.)

6) Pealing of bells at St. Peter's Basilica, Vatican. (a) Peal on two bells. (b) Pealing on Easter Sunday, 1965. (Courtesy, Frederic A. Fisher, United States Information Service in Rome, and RAI [Italian Radio TV System], Rome, Italy.)

Side Two

1) Swinging 20-ton Bourdon Bell at The Riverside Church, New York. (Courtesy, Riverside Radio WRVR, New York.)

2) Clock strike of Big Ben, Parliament Building, London. (Courtesy, Douglas Hughes, Whitechapel Bell Foundry, London.)

3) Change ringing on ten English handbells by five members of Ancient Society of College Youths, London. Peal being rung is "Stedman Caters." (Courtesy, Douglas Hughes, Whitechapel Bell Foundry.)

4) Bow Bells of London (ring of twelve), St. Mary-le-Bow Church. Change ringing of peal "Stedman Cinques." (Courtesy, Douglas Hughes, Whitechapel Bell Foundry, London.)

5) Clock strike at St. Paul's Cathedral, London. Five-ton hour bell, "Big Tom," is preceded by "ting-tang" chime. (Courtesy, Douglas Hughes, Whitechapel Bell Foundry.)

6) Change ringing at St. Paul's Cathedral, London. Members of Cathedral Company of Ringers play the peal "Stedman Cinques" on ring of twelve bells. On this occasion alternate changes are muffled from having a leather pad strapped to one side of each clapper. (Courtesy, Michael Morton, Ancient Society of College Youths, London.)

7) Lutine Bell at Lloyd's of London. The bell was retrieved from the French frigate *La Lutine*, wrecked off the Zuyder Zee in 1799. Hung in the main hall of Lloyd's since 1858, it is rung at the beginning and close of brokers' announcements: two strokes for good news; one for bad news, such as a ship sinking. (Courtesy, Douglas Hughes, Whitechapel Bell Foundry.)

8) Poreclain glockenspiel of thirty-seven bells at Meissen, Germany. Automatic play of "Es ist Feierabend" ('Tis Time for Leisure). (Courtesy, Mathias Mueller, Director of International Relations, German Democratic Republic [East Germany].)

9) Great Bell of Kyoto, Japan. Tolling New Year's arrival, with shouts of celebrants heard between strokes. (Courtesy, Joe Okada, The Sounds of Japan Associates, Kyoto.)

10) Shinnyo-Do Bell, Shinnyo-Do Temple, Kyoto, Japan. (Courtesy, Hideo Akashi, Nippon Hoso Kyokai [Japan Broadcasting Corp.], Tokyo.)

11) Mingun Bell, near Mandalay, Burma. (Courtesy, John Ewing, United States Information Service, Mandalay.)

12) Thirteen-bell *Zvon*, Monastery at Rostov Veliki, Russia. Five ringers, led by Alexander Butylin, demonstrate traditional bell ringing of Russian Orthodox Church. Largest bell weighs 36 tons, and set is regarded as the finest in Soviet Union today. Examples heard are excerpts from tape recording made in 1963, portions of which were incorporated in sound track for the Russian movie *War and Peace*. (Courtesy, Ministry of Culture, USSR.)

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